POCKET-BOOK

OF

PRACTICAL NAVIGATION

GIEVES

Pocket-Book of
Practical Navigation

BY

CAPTAIN H. C. J. GRANT
R.N.

GIEVES
PUBLISHING COMPANY, LIMITED
THE HARD, PORTSMOUTH

BY SPECIAL APPOINTMENT

TO HIS MAJESTY THE KING

JOHN HOGG
13 PATERNOSTER ROW, LONDON
1917

C

PART I

CONTENTS

SECTION (a).—CHANNEL NAVIGATION

SECTION (b).—COASTAL NAVIGATION

SECTION (c).—OCEAN NAVIGATION

Practical Navigation

INTRODUCTORY REMARKS

THIS Pocket-Book endeavours to inculcate methods to—

(*a*) Conveniently keep records of former experience for future guidance.
(*b*) Secure rapidity in obtaining results.
(*c*) Save labour, memory, and thought.
(*d*) Secure uniformity and symmetry, especially in working out sights.

Navigating difficulties may be classed as preventable and unpreventable.

Preventable difficulties consist of—

(*a*) Errors in steering the course.
(*b*) Errors in estimating the run.
(*c*) Errors in fixing the ship's position.

These errors can with care and diligence be greatly diminished.

Unpreventable difficulties consist of—

(*a*) Unknown tidal streams and currents.
(*b*) Bad weather.

(Causing errors in steering the course and estimating the run.)

(*c*) Fogs and thick weather.
(*d*) Clouds obscuring heavenly bodies.

(Preventing accurate fixing of the ship's position.)

(*e*) Floating dangers, derelicts, ice, etc.

These difficulties can only be countered by care, judgment, good look-out, and sounding.

In dealing with these difficulties, the following points should be borne in mind:—

In clear weather always navigate with the greatest care and accuracy, and obtain records of the procedure. This will give invaluable practice; also confidence in calculations made when the weather is thick or foggy.

In clear weather, if the course leads too near or too far from a danger, it is easy to alter when the danger is seen. This, however, should not occur at any time, and every allowance for currents, steering, and speed errors, etc., should be made, so that the ship is in the right place at the right time whether the danger is seen or not.

In laying a Course to clear a danger, the " Distance Off " the course is laid from the danger should depend on the distance to run from the last accurate " Fix." Thus, if a steering error of 1° is probable, the " Distance Off " should depend on such error.

In measuring the " Distance Run " by Patent Log or Revolutions, a possible error as a percentage of the distance from the last accurate " Fix " should similarly be guarded against.

Distance Run measured by Patent Log is generally too small, and by Revolutions generally too great. The measure by each should therefore always be compared.

Currents and Tidal Streams

Currents and tidal streams are dealt with in Section (*b*), where reference is made to the various publications on the subject.

No summary of the world's ocean currents is given in this book. The navigator should always consult the Wind and Current Charts and other publications rather than trust to memory or refer to a condensed review of the subject.

Soundings on charts are given for depths at Low Water Ordinary Springs. These depths may be reduced, and caution is necessary, as follows :—

(*a*) At the equinoxes on the coast of Europe, and generally at the solstices in the tropics.
(*b*) Perigee of the moon occurring at full and new moon.
(*c*) With a high barometer.
(*d*) With certain directions of the wind.
(*e*) When there is great diurnal inequality in the tides.

When navigating along the coast, indraught into bays and bights should be guarded against. Frequently there is an indraught at one end of an open bight and an outdraught at the other.

It should be remembered that the turn of tide off coasts is not often at the time of high and low water on shore.

If the tidal stream turns at half-tide rise or fall on shore it is termed " Tide and Half Tide " ; this generally occurs in open channels, and consequently the greatest velocity of the tidal stream is at high or low water on shore.

Tidal Atlases for the British Isles should be closely studied when navigating those coasts. No publication gives the total cumulative effect of a tidal stream on a ship, and this can only

be obtained by a record of practical experience, if possible in smooth water. Such records will be invaluable when making the same passage in similar tidal conditions, especially in a fog. For example :—If a record has been obtained entering the Thames estuary at a certain time of high water at Dover, it might, in a fog, on another occasion, be advisable to wait an hour or two for similar tidal conditions, if delay is immaterial.

Currents and tidal streams are affected by wind. This is frequently exaggerated, supposed wind effect on the current being in reality wind effect on the ship ; thus it may be observed the current frequently appears more normal steaming with the wind than against it.

It might also be assumed that if the wind lowered the tidal rise 5 per cent., the current velocity would be lessened 5 per cent. ; it must, however, be remembered that wind effect is on the surface water, the tidal rise may be caused by increased velocity of water below wave depth, the surface current being greatly modified.

Here again previous records giving the wind encountered should be valuable.

In laying off a Course where an unknown current may exist, a liberal allowance should be made for a possible dangerous current, based on the " Run."

In measuring the Distance to Run by Patent Log or Revolutions, allow similarly for a possible dangerous current, as a percentage of the distance to run.

Fogs and Thick Weather

Fogs are probably the navigator's greatest difficulty. Ability to navigate therein with confidence and certainty will be invaluable in wartime.

On the Course and Speed.—It is noteworthy how seldom Channel and Holyhead mail boats are delayed by fog. This is due to experience and the records of former passages in clear weather, embracing all conditions of the tidal streams. Such records are a great help in foggy weather and should be obtained on all occasions.

Simple and handy methods of keeping records are shown in Sections (*a*) and (*b*). It should be remembered that, in foggy weather, there being little or no wind, tidal streams and currents given on charts may be relied on to a far greater extent than in rough weather.

The speed of the ship is an important factor. The higher the speed, the less is the ship affected by steering errors and tidal streams and currents.

Other dangers, such as risk of collision, must be balanced against this advantage. This balance will differ in wartime from that in peace.

On Seeing.—The visibility in fog should be estimated whenever possible, and the ship's speed adjusted to the visibility and distance in which she can be stopped.

Visibility of buoys can be ascertained by noting the time of passing a buoy and the time it disappears. Visibility circles thus estimated and described round succeeding buoys will show when they may be expected to appear. The distance at which fishing boats and ships disappear will also indicate the visibility.

Steamers' positions in low-lying fogs are frequently detected by smoke-puffs above the fog, and in the North Sea steamers may frequently be thus detected 5 to 6 miles distant when light-vessels can only be seen half a mile distant. For this reason it is advisable to have a look-out aloft as high as possible.

Fogs round the British Isles and in the North Sea in summer are frequently very patchy and thick in places; they may be suddenly run into, and it is impossible to say over what area they may extend.

On Hearing.—The navigator must never implicitly rely on hearing sound signals, such as gun, syren, explosive report, horn, bell, gong, or whistle.

A submarine bell is probably the most reliable sound signal, but the ship must be fitted with a receiver.

A syren with high and low note may be inaudible in one note.

Sound may be thrown up and be audible aloft but not on deck.

The intensity or otherwise of a sound signal is no guide as to the distance of the apparatus, and very little guide as to the direction.

The inaudibility of a sound signal is no proof it is not sounding or that the ship is at a great distance.

Sound may travel further in one direction than in another.

Sound signals on buoys and unwatched light-vessels are generally operated by the motion of the sea, and in a calm may not sound.

Great caution should be exercised in approaching land in a fog, especially if relying on fog signals. Soundings are the only safe guide if the slope and nature of the bottom are defined.

Bad Weather

Bad weather and rough sea introduce errors in the course steered and the distance measured.

Allowance for steering errors should be based on the distance run on a course.

Distance measured by Patent Log is affected by the ship's pitching and by waves.

Distance by Patent Log, therefore, generally underestimates the Run as compared with the measure in smooth water.

The Patent Log will always underestimate the Run if unknown it is temporarily fouled by any floating matter.

Distance measured by Revolutions is affected by the ship's pitching and by wind pressure on the ship.

Distance by Revolutions, therefore, generally overestimates the Run as compared with the measure in smooth water.

The Revolutions will always overestimate the Run if the ship's bottom is foul.

It is always advisable to compare the Distance Run as measured by Patent Log or by Revolutions, and generally to take the mean.

Distance Run may be very accurately measured by Revolutions if the measure is corrected for wind, state of sea, and state of ship's bottom, for which purpose tables should be prepared. Distance by Revolutions, thus corrected, is perhaps the best distance measure to rely on when observations for fixing the position are unobtainable.

ESSENTIAL PRELIMINARY KNOWLEDGE

(1) Helm Orders

Orders for the helm should be given clearly, loudly, and *must* always be repeated by the helmsman.

Thus the officer conning the ship orders "*Starboard* 15," meaning 15° of Starboard helm.

The helmsman *repeats* "Starboard 15," and when the helm is over reports "15 Starboard."

Orders to move the helm from amidships or the normal must always be preceded by:—

(Left) "*Starboard*" ←—— or ——→ "*Port*" (Right)

when the upper half of the wheel and the ship's head move in the direction of the arrows.

Thus, "*Starboard* 15°" or "Starboard 1 point," the top of wheel and ship's head go to the *Left, i.e.* to *Port*; and "*Port* 15°" or "Port 1 point," the top of wheel and ship's head go to the *Right, i.e.* to *Starboard.*

"*Hard a-Starboard*" or "*Hard a-Port*" orders the helm the full amount to Starboard or Port respectively.

"*Ease the Helm*" or "Ease to 10°" orders the helm to be eased (but not to amidships), or eased to 10° respectively.

"*Midships*" orders the helm to be put amidships and *kept there* till the next order.

"*Meet her*" orders the helm to be put in a contrary direction to the last order preceded by "Starboard" or "Port"; to check the swing of the ship.

"*Steady*" is given when the ship is directly on her course. The helmsman repeats "Steady" and the degree in line with the "Lubber's Line."

For small changes of course a direct order to steer the desired course is generally given.

Thus, if steering 100° and it is wished to steer 110°, the order "*Steer* 110°" may be given.

When the helmsman is slightly off his course an order to correct him may be given thus:—

"2° to Starboard of your course."—The helmsman corrects by putting the helm to Starboard.

"3° to Port of your course."—The helmsman corrects by putting the helm to Port.

Note (1) On taking charge, always ascertain what helm the ship is carrying.
(2) Always use plenty of helm to start the ship in turning.
(3) By looking aft it can be seen more immediately when the ship commences to turn, or when her swing is checked, than by looking at the compass or ship's head.
(4) Give the orders "Ease the helm," "Midships," or "Meet her," as necessary, in good time, and always avoid swinging past the new course.
(5) In order to correctly note the degree in line with the "Lubber's Line" at the order "Steady," the helmsman must stand directly in rear of the compass.

(2) Compass Correction

Compass adjustment is not dealt with, so many works on the ›ject being extant. This is a technical subject for the expert o can make of it a special study.

Compass Course is the Course by Compass a vessel steers.
Magnetic Course is the Course a vessel would steer if the Compass North or 0° pointed to the North Magnetic Pole.
True Course is the Course a vessel would steer if the Compass North or 0° pointed to the True North Pole.

Deviation is the amount in degrees the Compass North or 0° ›nts E. or W. of the North Magnetic Pole when the ship's head ›n a given direction.

Deviation is marked E. or W. according as the Compass North 0° is E. or W. of the Magnetic North.

Variation is the amount in degrees the Magnetic North or points E. or W. of the earth's True North Pole.

Variation is marked E. or W. as the Magnetic North is E. or of the True North.

In the case of the Gyro Compass—

The Compass Course is the course by Compass the vessel steers.

The True Course is the course the vessel would steer if the ›mpass North or 0° pointed to the True North Pole instead of ›ng deflected by the speed of the ship.

The Deviation is the amount in degrees the Compass North or points E. or W. of the True North when the ship's head is in ›iven direction.

The Deviation varies with the speed and course of the ship as ›wn in the tables; it is greatest on N. or S. courses, and vanishes E. or W. courses.

EXAMPLES.—Variation 17° W., True Course 340°, gives Magnetic ›urse 357°.

Deviation 2° E., Magnetic Course 123°, gives Compass Course ›1°.

In this manner, with compasses graduated from 0° to 360° a clockwise direction, the course is quickly and easily corrected ›ntally for Variation and Deviation.

In the case of compasses graduated from 0° to 90° in each of › four quadrants, with the 90° in juxtaposition, the safer method to convert the Course (True or Compass) to the equivalent ›ding on a compass graduated from 0° to 360° clockwise, and ›n proceed as above, reconverting the result when obtained.

Thus: Variation 17° E., Deviation 2° E., True Course S. 50° E. ›nd the Compass Course.

True Course S. 50° E. = 130°; Magnetic Course = 113°; Compass ›urse = 111°.

Hence Compass Course = 180° − 111° = S. 69° E.

(3) Vessels' Fog and Distress Signals, and Lights

(Extracts from Regulations for Preventing Collisions)

Fog Signals

ARTICLE 15.—In fog, mist, falling snow, or heavy rainstorms, whether by day or night, the signals described in this Article shall be used as follows, viz. :—

(*a*) **A steam vessel having way upon her,** shall sound, at intervals of not more than 2 minutes, a prolonged blast with a whistle or syren.

(*b*) **A steam vessel under way, but stopped and having no way upon her**, shall sound, at intervals of not more than 2 minutes, two prolonged blasts, with an interval of about 1 second between them.

(*c*) **A steam fishing vessel, when trawling, dredging, or line-fishing,** shall give one blast of the steam whistle or syren every minute.

(*d*) **A sailing vessel under way** shall sound, at intervals of not more than 1 minute, when on the *Starboard Tack* one blast, when on the *Port Tack* two blasts in succession, and when with the wind *abaft the beam* three blasts in succession with a foghorn.

(*e*) **A vessel when at anchor,** shall, at intervals of not more than 1 minute, ring the bell rapidly for about 5 seconds.

(*f*) **A vessel when towing, a vessel employed in laying or picking up a telegraph cable,** and **a vessel under way which is unable to get out of the way** of an approaching vessel through not being under command, or unable to manœuvre as required by these Rules, shall, instead of the signals prescribed in subdivisions (*a*) and (*c*) of this article, at intervals of not more than 2 minutes sound three blasts in succession, viz. one prolonged blast followed by two short blasts.

A vessel towed may give this signal, and she shall give no other.

A wreck-marking vessel will sound a bell and gong alternately.

Regulations for Fog

ARTICLE 16.—Every vessel shall, in a fog, mist, falling snow, or heavy rainstorms, go at a moderate speed, having regard to the existing circumstances and conditions.

A steam vessel hearing, apparently forward of her beam, the fog signals of a vessel the position of which is not ascertained, shall, so far as the circumstances of the case admit, stop her engines and then navigate with caution until danger of collision is over.

Distress Signals

ARTICLE 31.—When a vessel is in distress and requires assistance from other vessels or from the shore, the following shall be the signals to be displayed by her, either together or separately, viz. :—

In the Daytime

(1) **A gun** or other explosive signal fired at intervals of about a minute.
(2) **The International Code Signal** of distress indicated by N.C.
(3) **The Distant Signal,** consisting of a square flag, having either above or below it a ball, or anything resembling a ball.
(4) **A continuous sounding** with any fog-signal apparatus.

At Night

(1) **A gun** or other explosive signal fired at intervals of about a minute.
(2) **Flames** on the vessel, as from a burning tar-barrel, oil-barrel, etc.
(3) **Rockets or Shells,** throwing stars of any colour or description, fired one at a time, at short intervals.
(4) **A continuous sounding** with any fog-signal apparatus.

Special Lights

(Including Fishing Lights North of Finisterre)

A Single White Light without side lights may be either—

(1) A pilot vessel under sail (these exhibit a flare-up light every 15 minutes).
(2) A sailing vessel trawling or dredging (these exhibit a white flare-up light on the approach of a vessel).
(3) A vessel at anchor, or possibly a fishing vessel with her fishing gear fast to a rock.
(4) An open fishing boat, either steamer or sailing, with outlying tackle extending not more than 150 feet horizontally from the boat into the sea-way ; if the tackle extends more than 150 feet, a second white light will be showing 3 feet at least below the other when vessels are approaching.
(5) A vessel being overtaken.

A Single White Light with side lights indicates a small steam vessel without the additional masthead light.

N.B. Side Lights.—Green on Starboard side and Red on Port side show from right ahead to two points (22° 30′) abaft the beam on either side. Each light has an arc of 112° 30′.

Two White Lights without side lights may be either—

(1) A vessel fishing with drift nets or lines.
(2) A steam vessel trawling and steering directly towards you.
(3) A wreck-marking vessel. (*N.B.*—Unless approaching directly at right angles to the vessel, the third light will also be seen.)

Two White Lights with side lights indicate an ordinary steamer carrying the additional masthead light.

Two Vertical White Lights with side lights may be either—

(1) A vessel towing another. (*N.B.*—She may also carry the additional main masthead light.)
(2) An ordinary steamer carrying the additional masthead light and steering directly towards you.

Three Vertical White Lights with side lights—

(1) A vessel towing more than one other vessel. (*N.B.*—She may also carry the additional main masthead light.)
(2) A vessel towing another with the additional main masthead light and steering directly towards you.

A Single Green Light or a Single Red Light indicate—

(1) A sailing vessel.
(2) A vessel in tow.

Two Vertical Red Lights.—A vessel not under command.

Two Vertical Lights, White over Red.—A steam pilot vessel.

Three Vertical Lights, Red, White, Red.—A telegraph ship at work and not under control.

Two Red Lights, one at each end of a vessel, and a red flare-up every 15 seconds.—A light-ship out of position, or adrift from her moorings.

Special Day Signals

Two Black Balls or Shapes.—A vessel not under control.

Red Ball, White Diamond, Red Ball.—A telegraph ship at work and not under control.

Basket or other efficient Signal.—A fishing vessel with nets or lines out.

Light-ship with Day Mark lowered or Balls or Shapes displayed.—A light-ship out of position, or adrift from her moorings.

(4) Steering Rules and Sound Signals

(Extracts from Regulations for Preventing Collisions)

Risk of Collision can, when circumstances permit, be ascertained by carefully watching the compass bearing of an approaching vessel. If the bearing does not appreciably change, such risk should be deemed to exist.

Two Steamships meeting

ARTICLE 18.—When two steamships are meeting end on, or nearly end on, so as to involve risk of collision, each should alter her course to starboard, so that each may pass on the port side of the other.

This Article only applies to cases where vessels are meeting end on, or nearly end on, in such a manner as to involve risk of collision, and does not apply to vessels which must, if both hold their respective courses, pass clear of each other.

The only cases to which it does apply are when each of the two vessels is end on, or nearly end on, to the other—in other words, to cases in which, by day, each vessel sees the masts of the other in a line, or nearly in a line, with her own; and, by night, to cases in which each vessel is in such a position as to see both the side lights of the other.

It does not apply by day—

(1) to cases in which a vessel sees another ahead crossing her own course;

or by night—

(1) to cases where the red light of one vessel is opposed to the red light of the other;
(2) or where the green light of one vessel is opposed to the green light of the other;
(3) or where a red light without a green light or a green light without a red light, is seen ahead;
(4) or where both red and green lights are seen anywhere but ahead.

Two Steamships crossing

ARTICLE 19.—When two steamships are crossing, so as to involve risk of collision, the vessel which has the other on her own starboard side shall keep out of the way of the other.

Steamship to keep out of way of Sailing Ship

ARTICLE 20.—When a steam vessel and a sailing vessel are proceeding in such directions as to involve risk of collision, the steam vessel shall keep out of the way of the sailing vessel.

Vessel not giving way to keep Course and Speed

ARTICLE 21.—Where by any of these Rules one of two vessels is to keep out of the way, the other shall keep her course and speed.

Note.—When, in consequence of thick weather or other causes, such vessel finds herself so close that collision cannot be avoided by the action of the giving-way vessel alone, she also shall take such action as will best aid to avert collision.

Avoiding crossing ahead

ARTICLE 22.—Every vessel which is directed by these Rules to keep out of the way of another vessel shall, if the circumstances of the case admit, avoid crossing ahead of the other.

Steamship giving way to slacken Speed

ARTICLE 23.—Every steam vessel which is directed by these Rules to keep out of the way of another vessel shall, on approaching her, if necessary, slacken her speed or stop or reverse.

Ships overtaking Others

ARTICLE 24.—Notwithstanding anything contained in these Rules, every vessel, overtaking any other, shall keep out of the way of the overtaken vessel.

Every vessel coming up with another vessel from any direction more than two points abaft her beam, *i.e.* in such a position with reference to the vessel which she is overtaking, that at night she would be unable to see either of that vessel's side lights, shall be deemed to be an overtaking vessel ; and no subsequent alteration of the bearing between the two vessels shall make the overtaking vessel a crossing vessel within the meaning of these Rules, or relieve her of the duty of keeping clear of the overtaken vessel until she is finally past and clear.

As by day the overtaking vessel cannot always know with certainty whether she is forward of or abaft this direction from the other vessel, she should, if in doubt, assume she is an overtaking vessel and keep out of the way.

In Narrow Channels

ARTICLE 25.—In narrow channels every steam vessel shall, when it is safe and practicable, keep to that side of the fairway or mid-channel which lies on the starboard side of such vessel.

Keeping clear of Fishing Boats

ARTICLE 26.—Sailing vessels under way shall keep out of the way of sailing vessels or boats fishing with nets, lines, or trawls. This Rule shall not give to any vessel or boat engaged in fishing the right of obstructing a fairway used by vessels other than fishing vessels or boats.

Proviso as to Dangers of Navigation, etc.

ARTICLE 27.—In obeying and construing these Rules, due regard shall be had to all dangers of navigation and collision, and to any special circumstances which may render a departure from the above Rules necessary in order to avoid immediate danger.

Two Sailing Vessels meeting

ARTICLE 17.—When two sailing vessels are approaching one another so as to involve risk of collision, one of them shall keep out of the way of the other, as follows, viz. :—

(*a*) A vessel which is running free shall keep out of the way of a vessel which is close hauled.

(*b*) A vessel which is close hauled on the port tack shall keep out of the way of a vessel which is close hauled on the starboard tack.

(*c*) When both are running free with the wind on different sides, the vessel which has the wind on the port side shall keep out of the way of the other.

(*d*) When both are running free with the wind on the same side, the vessel which is to windward shall keep out of the way of the vessel which is to leeward.

(*e*) A vessel which has the wind aft shall keep out of the way of the other vessel.

Sound Signals for Vessels in sight of one another

ARTICLE 28.—The words "short blast" used in this Article shall mean a blast of about one second's duration.

When Vessels are in sight of one another, a steam vessel under way, in taking any course authorised or required by these Rules, *shall indicate* that course by the following signals on her whistle or syren, viz. :—

One short blast to mean—"I am directing my course to Starboard."

Two short blasts to mean—"I am directing my course to Port."

Three short blasts to mean—"My engines are going full speed astern."

Note.—In some narrow channels four short blasts by a steam vessel shall indicate she is unable to get out of the way of small vessels in the channel; these latter must then use their utmost endeavour to keep clear of the fairway.

Rhyming Memoranda for Steam Vessels' Rule of the Road

ARTICLE 18.—

(1) Green and red
Dead ahead,
Port the helm,
Show the red.

(2) Green to green
Or red to red—
Touch not the helm
But go ahead.

Articles 19 and 22.—

If from green is seen a red,
In general don't cross ahead;
To keep clear must *your* ship be led.

If from red is seen a green,
Keep course and speed and see
Your own lights brightly sheen.

(5) Charts

Charts used in navigation are of three kinds, viz. :—

(*a*) Plane Projection or Plans.
(*b*) Mercator's Projection or Mercator's Charts.
(*c*) Gnomonic Projection.

(*a*) Plans

Plans are constructed in order that bearings may be represented thereon by straight lines, and distances may be represented on a reduced scale of actual distances.

Plans are drawn on a large scale of small portions of the surface of the earth on the supposition that the surface of the earth is a plane flat surface. As the portion of the surface of the earth represented is small, error due to the curvature of the earth is immaterial.

Plans are of the largest convenient scale, the original scale of the survey being generally employed. Charts of harbours and anchorages are usually plans.

The Natural Scale, always given on a plan, shows the size of the plan compared with the corresponding surface of the earth.

Thus, " Natural Scale $\frac{1}{7300}$ " means the plan is $\frac{1}{7300}$ of the surface of the earth represented.

The scale of Latitude and Distance, in nautical miles or cables, is always given on a plan.

The scale of Longitude is generally given.

The scale of Yards is generally given.

These scales can all be ascertained from the Natural Scale.

Thus, if the Natural Scale is $\frac{1}{7300}$, then—

1 Sea Mile or 1′ of Latitude $= \frac{1}{12}(6082{\cdot}66 \div 7300)$ inches.

1′ of Longitude $= \frac{1}{12}(6082{\cdot}66 \div 7300 \times \text{Cosine Latitude})$ inches.

1000 Yards $= \frac{1}{12}(3000 \div 7300)$ inches.

Note (1).—The number of feet in a nautical mile varies slightly with the latitude —6082·66 feet may be taken as an average value. The correct value is given in Wharton's *Hydrographical Surveying*.

Note (2).—Calculated scales seldom agree with scales printed on charts, owing to the distortion of the latter. As distortion affects the chart and the scale printed thereon almost equally, no appreciable error is found in measuring distances on a plan with this printed scale. The printed scale should therefore be used in preference to calculated scales.

Note (3).—Longitude scales may be constructed graphically from the latitude scale thus :—

(*a*) Lay off from zero on the latitude scale a line making with the latitude scale an angle equal to the latitude of the plan.
(*b*) From the graduations on the latitude scale drop perpendiculars on to the above line. These points are the corresponding graduations of longitude.

In future, modern plans, and older plans when convenient, will be graduated for latitude and longitude on the framework. This will give easy reference to Astronomical Positions.

Observation Spot.—The latitude and longitude of one spot on a plan marked " Obs. Spot " is always given under the title.

Bench Mark, B.M. $\bigwedge$, is a point whose height above the datum or water-level of the survey (generally L.W.O.S.) is given. Its position is marked on all plans.

The Soundings on plans are generally given in feet or fathoms above Low Water Ordinary Spring Tides (L.W.O.S.), as stated in the title. Care should be taken always to refer to the measure of the soundings given in the title.

(*b*) Mercator's Charts

Mercator's Charts are constructed in order that " courses " (which cut all meridians at the same angle) may be represented thereon by straight lines.

In a Mercatorial Projection the longitude scale, instead of decreasing towards the Pole as on a globe, remains constant irrespective of the latitude; thus the meridians are parallel, and in order that the longitude scale may remain constant, it increases on the chart proportionately to the secant of the latitude.

Similarly, in order to measure distances correctly, and in order to preserve the proportions of the chart with the proportions of the earth's surface, the latitude scale *in each latitude* must also increase on the chart proportionately to the secant of the latitude. This is why the Latitude Scale at the side of a Mercator's Chart gradually increases towards the Pole.

The Latitude Scale for any latitude, therefore, may be found thus :—

$$1' \text{ of latitude} = 1' \text{ of longitude (on the scale of the chart)} \times \text{Secant of the latitude of the place.}$$

For example :—The distance between two meridians 1° apart, on a Mercator's Chart, measured by the Latitude Scale at the Equator is 60 nautical miles. In latitude 60° the distance between the same two meridians measured by the Latitude Scale in latitude 60° is only 30 miles, which is the actual distance these meridians are apart in that latitude on the earth.

Mercatorial Latitude of a place is the length on Mercator's Projection representing the distance between the latitude of the place and the Equator. Now, as each mile of latitude on a Mercator's Chart is represented by :—

$$1 \text{ mile of longitude (on the scale of the chart)} \times \text{Secant of the latitude of the place,}$$

therefore the Mercatorial Latitude of a place is the sum of :—

Each $1' \times$ Secant of each latitude (successive latitudes increasing by $1'$).

Thus Mercatorial Latitude of a place is :—

$1' \times \sec (0° \tfrac{1}{2}') + 1' \times \sec(0° 1\tfrac{1}{2}') + 1' \times \sec (0° 2\tfrac{1}{2}')$, and so on to the latitude of the place.

For accurate determination, smaller units and smaller increases of latitude than $1'$ should be employed, and accurate determination can only be effected by employment of the calculus.

It is clear, however, that by summation as above, or by the aid of the calculus, a coefficient can be obtained for each latitude, which coefficient, multiplied by the length on the chart representing one minute of longitude, will give, on the same scale, the length representing the distance of the parallel of latitude referred to, from the Equator.

The Mercatorial Part of any Latitude is the coefficient by which one minute of longitude on the scale of the chart must be multiplied in order to obtain the Mercatorial Latitude of the place.

The Meridional Difference of Latitude between any two places is the length on Mercator's Projection representing the distance between the latitudes of the two places.

Note.—On Mercator's Charts bearings can only be represented by straight lines if the distance is small. Thus on a Mercator's Chart the straight line joining Land's End and New York is the "Course" from the one to the other. The bearing between these two places is the first course on the Great Circle passing through both places.

(*c*) Gnomonic Charts

Gnomonic Charts, also called Polar or Great Circle Charts, are constructed in order that "Bearings," *i.e.* Great Circles, may be represented thereon by straight lines.

In Gnomonic Projection the charts are constructed by projection on a plane touching the globe. The point at which the plane touches the globe is called the "Point of Tangency." The centre of projection is the centre of the globe.

In Polar Charts the Point of Tangency is the Pole ; meridians are therefore represented by radii from the Point of Tangency, and latitude parallels by concentric circles with centre at the intersection of the meridians. The distance apart of the latitude parallels increases from the Pole as the cotangent of the latitude.

Notes on the Use of Charts, etc.

(1) The largest-scale chart, whether Mercator or Plan, should always be used. Large-scale charts are the most accurate, first corrected, and the best surveys. The largest-scale chart can be ascertained from the Index Chart in the "Sailing Directions."

(2) Plans are generally the most accurate charts, as they are of large scale and—

- (*a*) Very carefully and accurately surveyed ;
- (*b*) Very closely and accurately sounded ;
- (*c*) By the nature of the projection accurate for fixing positions.

(3) Charts of the most recent date should always be used. The date is given in the title-plate, and date of publication in the centre of the lower edge of the chart. Charts are issued corrected to the dates given of the latest Large and Small Corrections.

Large Corrections are those that require a new edition of the chart to be made, that require to be made on the plate, and that are too large or too extensive to be conveniently made by hand.

Dates of Large Corrections or New Editions are printed in the right centre of the lower edge of the chart, thus: "Large Corrections, June 10; June 12"; or more recently thus: "New Editions, December 1908; 24th December 1914."

Small Corrections are those for which a new edition is unnecessary or that can be made by hand.

Dates of Small Corrections are printed on the left lower edge of the chart, with the month in Roman numerals; thus: "Small Corrections, V. 10; VII. 14," indicates small corrections in May 1910 and July 1914.

Asterisks after the year indicate the number of corrections; thus: "Small Corrections, V. 10 **," indicates two corrections since May 1910.

In future only the date of Small Corrections since the last "New Edition" will be shown. Thus, "V. 12" shows the chart is corrected to May 1912. Small Corrections are also issued in Notices to Mariners. Such corrections and additions should be inserted in red ink, care being taken not to obliterate other details.

Erasures are to be made by a single red line.

The dates and numbers of such corrections, additions, or erasures are to be inserted in the left lower edge of the chart where "Small Corrections" is printed, thus: "12.1763," *i.e.* 1912; number of Notice to Mariners, 1763.

Sometimes important corrections are issued as diagrams to be pasted on the chart.

Duplicates of Notices to Mariners should be pasted in the Sailing Directions (*v.* page 49) for future reference should greater detail of the Notice be required.

Wrecks, with the year, should be inserted in red ink, with the date, thus: " Wreck 1912."

Intended or temporary changes issued in Notices to Mariners

should be inserted in lead pencil, and inked in in red or erased when confirmed or otherwise.

Largest-scale charts should always be corrected first; smaller-scale charts also affected should be corrected with detail in accordance with that already on the chart, or with as much as the scale of the chart permits. Thus, whereas large-scale charts have details of lights, their sectors, and buoys, in smaller-scale charts these are omitted.

Note.—Charts are frequently corrected in small details that do not affect safe navigation. For these no date is inserted; consequently charts of the same Large and Small Corrections may differ slightly.

(4) **To describe a chart**, always give—

(*a*) The title	thus	Harwich Harbour	(in title plate)
(*b*) The date of publication	,,	1907	(centre of lower edge)
(*c*) The number of the chart	,,	No. 6733	(right-hand lower corner).
(*d*) The date of latest Large Correction	,,	Large Correction June 1910	(centre of lower edge).
(*e*) The date of latest Small Correction	,,	Small Correction, VII. 1912	(left-hand lower corner).

(5) **Soundings.**—It is stated in the title whether the soundings are in feet or fathoms. This should always be referred to, especially when using a strange chart.

The value of a chart is best judged by the soundings, by noting whether these are regular or uneven, and whether they are full or scanty. If the soundings are irregular, *i.e.* not plotted in regular straight lines, it may be assumed that the survey is not in great detail. If the soundings are scanty, undetected dangers may exist.

Charts with no fathom lines should always be regarded with great suspicion. The omission is generally due to soundings being scanty and the bottom uneven.

The Navigator should avoid—

(*a*) Places showing inequalities in depth, especially with a rocky bottom, as undiscovered rocks or shoals may exist.

(*b*) Blank spaces, as these are unsounded, more especially so should the surrounding depths be shallow or irregular.

(*c*) Isolated soundings with a ring around, especially if the surrounding depths are shallow or irregular.

(*d*) Rocky shores and patches. He should assume foul grounds, unless close and regular soundings prove otherwise.

(*e*) In general coast charts,—approaching too closely the 10-fathom line, especially if the coast is rocky, as this line is cautionary only, and not an infallible indication of greater depths seaward.

(*f*) The 5-fathom line. This line should always be considered a danger line.

(*g*) Small-scale charts, as errors may arise in fixing.

(6) **Positions of Objects** are indicated as follows :—

Light-vessel, buoy, or beacon is the centre of the base and is usually indicated by a small circle.

Coast line at H.W.O.S. (*v.* page 41) is a thin black continuous line.

Coast line at L.W.O.S. (*v.* page 40) is the limit of the symbols indicating nature of foreshore.

Bottom of a cliff is a line in the correct position of the bottom.

The line representing the top of a cliff is not shown in its correct position. This line indicates the height of the cliff by its distance from the line indicating the bottom.

Hills will in future be represented by contour lines.

Buoys should be regarded as warnings only, and not as infallible navigation marks.

Gas-buoys must not be implicitly relied on. They may get out of order, and in bad weather it may be impossible to recharge them.

(7) **Distortion of Charts in Process of Printing.**—Charts become distorted in printing, and consequently may differ somewhat from the plate.

Distortion varies with the quality of the paper, but is not sufficiently serious to affect safe navigation.

An accurate series of angles may not always fix in the same spot on this account.

Near objects should always be used in "fixing" (*v.* page 99) to lessen the effects of distortion.

(8) **Lights.**—Arcs or circles round lights indicate the bearings between which the lights or their coloured sectors may be seen. These arcs do not show the distance of visibility.

The Visibility, in miles, shown against a light is calculated for the observer's height of eye of 15 feet, the light or centre of the lantern being on that horizon. Visibility may be increased by glare, refraction, reflection from clouds, greater height of eye, or by the state of the atmosphere. It may be lessened by lesser height of eye, and thick atmospheric conditions.

Atmospheric penetrating power of a light varies greatly with the nature of the light and the illuminant used.

If, when a light is first seen, it disappears when the eye is immediately lowered several feet, the light is probably just on the observer's horizon.

(9) **Laying off Courses.**

(*a*) Place the parallel rulers on the Course on the compass engraved on the chart.

(*b*) See the ruler edge cuts the compass circumference 180° apart.

(*c*) Move the rulers carefully and rule a parallel through the Departure Point.
(*d*) Move the rulers back to the compass: they should lie on the original course.

For greater accuracy, especially with rolling rulers, rule two courses through the Departure Point as above, reversing the ruler; in good rulers these courses should coincide; if they do not, use as Course the bisector of the angle formed.

Notes.—(1) A magnetic compass is generally engraved on Plans and on Mercator's Charts.
(2) The variation given on a chart is subject to two changes: (*a*) annual change; (*b*) geographical change.
(3) The date of the variation is given on the compass, and the annual change, and whether increasing or decreasing, is given in the title-plate.
(4) Magnetic compasses are re-engraved when the annual change amounts to 2° 49′.
(5) The geographical change of variation is given on the Variation Charts. Where the geographical change is rapid, isogonic lines or lines of equal variation are also shown, or more than one magnetic compass is engraved, showing the variation for proximate areas, or a true compass is engraved and in addition isogonic lines are shown.

(10) **Measuring Distances.**—Distances on Plans or on Mercator's Charts are measured by the Latitude Scale. In measuring distances the latitude scale, that lies between the latitude parallels that include the run of the ship, should be used as far as possible.

Thus, if steaming due west in latitude 60°, measure the distance by the 10 miles on the latitude scale between 59° 5′ and 60° 5′.

Explanation of Signs and Abbreviations of frequent occurrence on the more recent Charts issued by the Hydrographic Department, Admiralty.

General Remarks.—Charts are generally drawn on the True Meridian; if otherwise, a True Meridian is given on the chart.

Soundings are expressed in feet or fathoms, as stated in the title of the chart.

1 fathom = 6 feet = 1·828766 metres.

Underlined figures, on rocks and banks which uncover, express the heights in feet above the datum of the chart, unless otherwise stated.

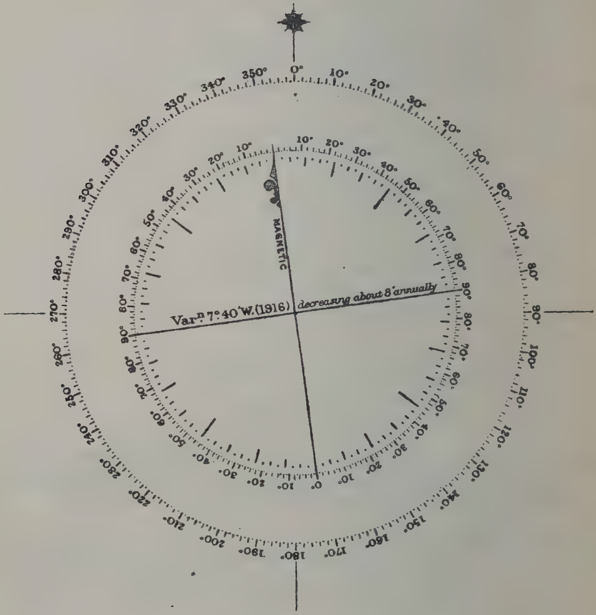
All heights (except those expressed in underlined figures as above) are, unless otherwise stated, given in feet above mean high water springs, or, in places where there is no tide, above the level of the sea.

The natural scale is the proportion which the scale of the chart bears to the actual distance represented, and is shown thus—$\frac{1}{12,150}$.

A sea mile is the length of a minute of latitude at the place, and a cable is assumed to be a tenth part of a sea mile.

The figures in brackets in the bottom right-hand corner of a chart, thus—(38·43 × 25·49) are the dimensions of the plate in inches between the innermost graduation or border lines.

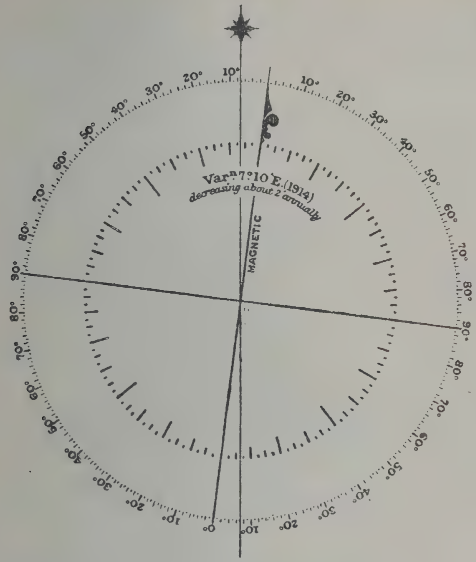
All longitudes are referred to the meridian of Greenwich.



Pattern of Compass adopted after June 1911, now being engraved on the Chart Plates when new compasses are required.

Note.—When a compass of the above pattern is shown on the chart, bearings are given both true and magnetic, thus—298° (N. 54° W. Mag.), and this is stated in the title.

The figures in brackets after the Variation denote the year for which it is given.



Pattern of Compass (prior to June 1911) drawn on the Magnetic Meridian.

The figures in brackets, either before or after the Variation, denote the year for which it is given.

All bearings are magnetic, except when otherwise stated, and are referred to the nearest compass on the chart.

General Abbreviations.

A. (Agios), *Saint* (*Greek*).
ab$^{t.}$, *about*.
Anch$^{e.}$, *Anchorage*.
Anc$^{t.}$, *Ancient*.
Approx., *Approximate*.
Arch$^{o.}$, *Archipelago*.

B., *Bay, Black*.
B. (Basse), *Shoal* (*French*).
B$^{a.}$ (Bana), *Cape or Point* (*Japanese*).
Bat$^{y.}$, *Battery*.
B$^{g.}$ (Berg), *Mountains* (*German*); *Cape* (*Netherlands*).
B$^{k.}$, B$^{ks.}$, *Bank, Banks*.
B.M. (⩚), *Bench Mark*.
B$^{n.}$, B$^{ns.}$, *Beacon, Beacons*.
Bo. (Bogha), *Sunken Rock* (*Gaelic*).
B$^{r.}$ (Besar), *Great* (*Malay*).
Br., *Bridge*.
B$^{t.}$ (Bukit), *Hill* (*Malay*).

C., *Cape.*
Cas., *Castle.*
Cath., *Cathedral.*
C.G., *Coast Guard.*
Ch., *Church or Chapel.*
Chan., *Channel.*
Ch$^{y.}$, *Chimney.*
Conspic., *Conspicuous.*
Cov., *Covers, Covered.*
Cr., *Creek.*

D., *Doubtful.*
dist., *distant.*
Dr., dr., *Dries.*

E., E$^{n.}$, Eil$^{n.}$, (Eilean), *Island, Islands* (*Gaelic*).
E.D., *Existence doubtful.*
Ens$^{a.}$ (Ensenada), *Bay or Creek* (*Spanish*).
Estab$^{t.}$, *Establishment.*
Est$^{o.}$ (Estero), *Estuary* (*Spanish*).

F. (Fiume), *River* (*Italian*).
F$^{d.}$ (Fjord, Fjard), *Fiord* (*Norwegian or Danish, Swedish*).
Fl. (Flu), *Sunken Rock* (*Norwegian*).
Fl$^{ne.}$ (Fluene), *Rocks* (*Norwegian*).
F$^{m.}$, f$^{ms.}$, Fathom, Fathoms.
F.S., *Flagstaff.*
f$^{t.}$, ft., *foot or feet.*
F$^{t.}$, *Fort.*

G., *Gulf.*
G$^{a.}$ (Gawa), *River* (*Japanese*).
G$^{d.}$, G$^{de.}$, (Grand), *Great* (*French*).
G$^{g.}$ (Gunong), *Mountain* (*Malay*); (Gusong), *Shoal* (*Malay*).
Gov$^{t.}$, *Government.*
Gr$^{d.}$ (Grund), *Shoal* (*German, Norwegian*).
G$^{t.}$, Gr$^{t.}$, *Great.*
G.T.S., *Great Trigonometrical Survey Station* (*India*).

h., hrs., *hour, hours.*
H$^{a.}$ (Hana), *Point* (*Japanese*).
H$^{d.}$, *Head.*
H$^{m.}$ (Holm), *Island* (*Norwegian or Danish*).
H$^{n.}$, *Haven.*
H$^{ne.}$ (Holmene), *Islands* (*Norwegian or Danish*).
Ho., *House.*
H$^{r.}$, *Harbour, Higher.*

I., I$^{t.}$, *Island, Islet.*
I$^{s.}$, *Islands, Islets.*
in., *inches.*

J., Jeb. (Jebel), *Mountain* (*Arabic*).
J$^{a.}$ (Jima), *Island* (*Japanese*)
Jez$^{t.}$ (Jezirat), *Island* (*Arabic*).

K$^{g.}$ (Kampong), *Village* (*Malay*).
K$^{g.}$ (Karang), *Coral Reef* (*Malay*).
K$^{l.}$ (Kechil), *Small* (*Malay*).

L., *Lake, Loch, Lough.*
L. (Lilla, Lille), Lit., *Little* (*Swedish, Norwegian, or Danish*).
L., L$^{a.}$, Lag$^{n.}$, *Lagoon.*
Lat., *Latitude.*
L.B., *Life Boat.*
L.B.S., ,, ,, *Station.*
L$^{dg.}$, *Leading* (*Lights or Beacons*) ; *Landing* (*Place*).
L$^{e.}$, L$^{es.}$, Ledge, Ledges.
Long., *Longitude.*

L$^{r.}$, *Lower.*
L.S.S., *Life Saving Station.*
L^{t}. Ho., *Lighthouse.*
L$^{t.}$ Ves., *Light Vessel.*

m., *miles, minutes.*
min., *minutes.*
Mag., *Magnetic.*
Mag$^{z.}$, *Magazine.*
Mid., *Middle.*
Mon$^{t.}$, *Monument.*
Mon$^{y.}$, *Monastery.*
M$^{t.}$,-M$^{te.}$, *Mountain.*
M$^{th.}$, *Mouth.*

N$^{o.}$, *Number.*

Obs$^{n.}$ Spot +, *Observation Spot.*
Obs$^{y.}$, *Observatory.*
Occas$^{l.}$, *Occasional.*
Off., *Office.*
Ord., *Ordinary.*

P., P$^{to.}$, *Port, Porto, Puerto.*
Pag., *Pagoda.*
Pass., *Passage.*
P.A., *Position approximate.*
P.D., *Position doubtful.*
Pen$^{la.}$, *Peninsula.*
P$^{k.}$, *Peak.*
P$^{o.}$ (Pulo), *Island* (*Malay*).
P.O., *Post Office.*
Pos$^{n.}$, *Position.*
Prom$^{y.}$, *Promontory.*
Prov$^{l.}$, *Provisional.*
P$^{t.}$, P$^{ta.}$, P$^{te.}$, *Point.*

R., *River.*
R.C., *Roman Catholic.*
R$^{d.}$, R$^{ds.}$, *Road, Roads.*
Rem$^{ble.}$, *Remarkable.*
R$^{f.}$, *Reef.*
R$^{k.}$, R$^{ks.}$, *Rock, Rocks.*
R.S., *Rocket Station.*
Ru. (Rudha), *Point* (*Gaelic*).
Ru., *Ruin.*
R$^{y.}$, *Railway.*

s., *seconds.*
S., S$^{n.}$, S$^{o.}$, S$^{t.}$, S$^{ta.}$, S$^{to.}$, *Saint.*
S$^{a.}$ (Sima or Shima), *Island* (*Japanese*); (Serra or Sierra), *Mountains* (*Spanish*).
S$^{d.}$, *Sound.*
Sem., *Semaphore.*
Sg., Sg$^{r.}$ (Sgeir), *Rock, Rocks* (*Gaelic*).
Sh., *Shoal.*
S$^{i.}$ (Sidi), *Tomb* (*Arabic*); (Sungi), *River* (*Malay*); (Saki), *Cape or Point* (*Japanese*).
Sig., *Signal.*
Sk$^{ne.}$ (Skierene, Skjaerene), *Rocks* (*Swedish, Norwegian, or Danish*).
Sk$^{r.}$ (Skär or Skier, Skjaer), *Rock* (*Swedish, Norwegian, or Danish*).
St. (Stor), *Great* (*Norwegian*), *Street.*
St$^{n.}$, *Station.*
Str., *Strait.*
S.B., *Submarine Bell* (*worked by wave action*).
S.F.B., *Submarine Fog Bell* (*worked electrically from a shore or other station*).

Tel., *Telegraph.*
Temp$^{y.}$, *Temporary, Temporarily.*
T$^{g.}$ (Tanjong), *Point* (*Malay*).
T$^{k.}$ (Telok), *Bay or Cove* (*Malay*).
T$^{r.}$, T$^{re.}$, *Tower.*

Uj$^{g.}$ (Ujong), *Cape or Point* (*Malay*).
Uncov., *Uncovers, Uncovered.*

V$^{a\cdot}$ (Villa), *House or Town.*
Var$^{n\cdot}$, *Variation.*
Vel., *Velocity.*
Vil., *Village.*
Vol., *Volcano.*

W. (Wadi), *River (Arabic).*
Wh$^{f\cdot}$, *Wharf.*

W.T., *Wireless Telegraph Station.*

Y$^{a\cdot}$ (Yama), *Mountain (Japanese).*
Y$^{ds\cdot}$, *Yards.*

Z$^{i\cdot}$ (Zaki), *Cape or Point (Japanese).*

Quality of the Bottom

b., *blue.*
blk., *black.*
br., *brown.*
brk., *broken.*

c., *coarse.*
cal., *calcareous.*
chk., *chalk.*
choc., *chocolate.*
cin., *cinders.*
cl., *clay.*
crl., *coral.*

d., *dark.*
di., *diatom.*

f., *fine.*
for., *foraminifera.*

g., *gravel.*
gl., *globigerina.*
gn., *green.*
grd., *ground.*
gy., *gray.*

h., *hard.*

l., *large.*
lv., *lava.*
lt., *light.*

m., *mud.*
mad., *madrepore.*
man., *manganese.*
ml., *marl.*
mus., *mussels.*

oys., *oysters.*
oz., *ooze.*

peb., *pebbles.*
pt., *pteropod.*
pum., *pumice.*

r., *rock.*
rad., *radiolaria.*

s., *sand.*
sc., *scoriæ.*
sft., *soft.*
sh., *shells.*
shin., *shingle.*
sm., *small.*
sp., *sponge.*
spk., *specks, speckled.*
st., *stones.*
stf., *stiff.*
stk., *sticky.*

t., *tufa.*

vol., *volcanic.*

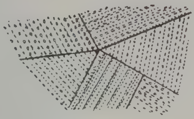
w., *white.*
wd., *weed.*

y., *yellow.*

Conventional Signs

Trees

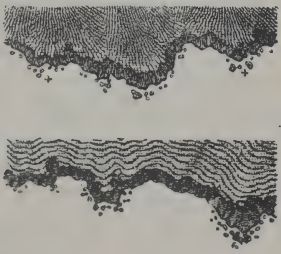
Cultivated Land



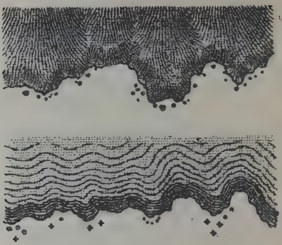
Swampy, Marshy, or Mossy Land

Sand Hills or Dunes

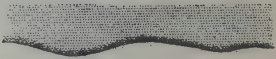
Cliffy Coast Line



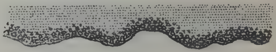
Steep Coast



Sandy Shore

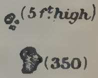


Stony or Shingly Shore



Mangroves

Figures bracketed against islands and rocks express the Heights in Feet above Mean High Water Springs, or above the sea in cases where there is no tide.



Towns, Villages, or Houses

Villages or Houses

Roads

Track or Footpath

Railway

Tramway

Churches or Chapels

Temples

Windmill

Triangulation Station

Beacon, Chimney, Flagstaff, or other fixed points

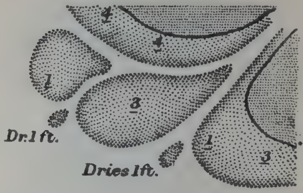
Lights, Position of

---

* Rocky Ledges and Isolated Rocks, dry at Mean Low Water Springs

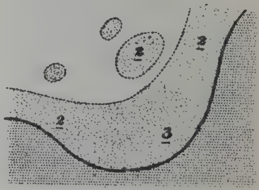
* The Underlined Figures, on the Rocks and Banks which uncover, express the heights in feet above the datum of the chart, unless otherwise stated.

* Sandy Beach and Banks, dry at Mean Low Water Springs

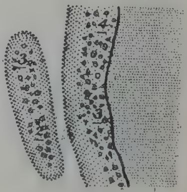


* Stones, Shingle, or Gravel, dry at Mean Low Water Springs

* Mud Banks, dry at Mean Low Water Springs

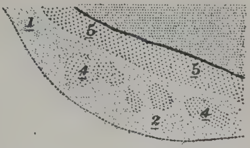


* Sand and Gravel or Stones, dry at Mean Low Water Springs

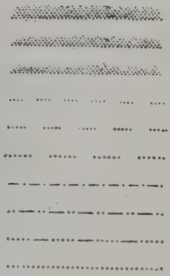


* The Underlined Figures, on the Rocks and Banks which uncover, express the heights in feet above the datum of the chart, unless otherwise stated.

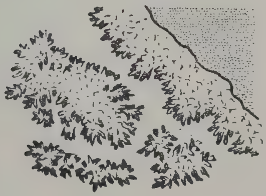
* Sand and Mud, dry at Mean Low Water Springs



Signifies	1 fathom line	
,,	2 ,, ,,	
,,	3 ,, ,,	
,,	4 ,, ,,	
,,	5 ,, ,,	
,,	6 ,, ,,	
,,	10 ,, ,,	
,,	20 ,, ,,	
,,	50 ,, ,,	
,,	100 ,, ,,	



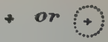
Coral Reefs



Rock awash at Mean Low Water Springs ✱ or (✱)

* The Underlined Figures, on the Rocks and Banks which uncover, express the heights in feet above the datum of the chart, unless otherwise stated.

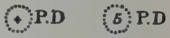
Rock with less than 6 feet of water over it at Mean Low Water Springs



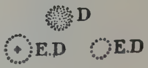
On small-scale charts, this symbol is used for rocks with greater depths of water over them.

Rocks with limiting Danger line

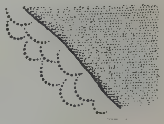
Rock or Shoal, the Position of which is Doubtful



Reported Rock or Shoal, the Existence of which is Doubtful



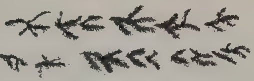
Breakers along a Shore



Overfalls and Tide Rips

Eddies

Kelp

Beds of Edible Seaweed 

Signifies no Bottom found at the depth expressed $\dot{\overline{10}}$ $\dot{\overline{100}}$

Anchorage for large vessels 

" " small " 

Fishing Stakes 

Wrecks

Where depth over is known $5\frac{1}{2}$ *Wreck (1911)*

Partially or wholly submerged, where depth over is unknown  *Wreck (1911)*

Lights

✪ ✱ •, *Lights, Position of.*
L$^{t.}$, L$^{ts.}$, *Light, Lights.*
*L$^{t.}$ Alt., *Light, Alternating.*
L$^{t.}$ F., *Light, Fixed.*
L$^{t.}$ Fl., *Light, Flashing.*
L$^{t.}$ Occ., *Light, Occulting.*
L$^{t.}$ Rev., *Light, Revolving.*
L$^{t.}$ F. Fl., *Light, Fixed and Flashing.*
†L$^{t.}$ Gp. Fl. (3), *Light, Group Flashing.*
†L$^{t.}$ F. Gp. Fl. (4), *Light, Fixed and Group Flashing.*
†L$^{t.}$ Gp. Occ. (2), *Light, Group Occulting.*
*Alt., *alternating.*
ev., *every.*
fl., fl$^{s.}$, *flash, flashes.*
G., G$^{n.}$, *Green.*
Gp., *Group.*
hor$^{l.}$, *horizontal* (*Lights placed horizontally*).
irreg., *irregular.*
m., *miles.*
min., *minute or minutes.*
obsc$^{d.}$, *obscured.*
‡occas$^{l.}$, *occasional.*
R., *Red.*
sec., *second or seconds.*
(U.), *Unwatched.*
vert$^{l.}$, *vertical* (*Lights placed vertically*).
vis., *visible.*
W., Wh., *White.*

* Alt. (Alternating) signifies a Light which alters in colour.

† The number in brackets, after the description of Group Flashing or Group Occulting Lights, denotes the number of flashes or eclipses in each group.

‡ Occasional Fog Signal means a signal which is only given in answer to vessels' signals.

The height given against a light is the height of the focal plane of the light above Mean High Water Spring Tides, or above the sea level in cases where there is no tide.

The visibility of lights is given in nautical miles, assuming the eye of the observer to be 15 feet above the sea.

Bearings of Lights are given from seaward.

Buoys and Beacons

Light Buoys

Bell Buoys

Can Buoys

Conical Buoys

Spherical Buoys

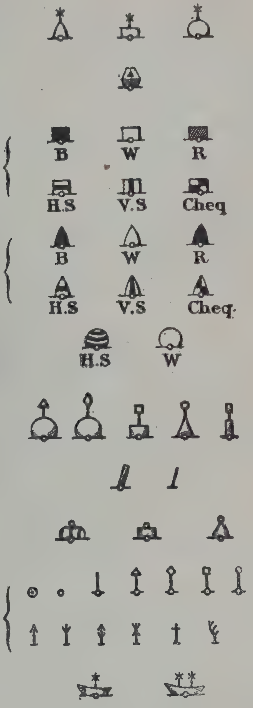
Buoys with Topmarks

Spar Buoys

Mooring Buoys

Fixed or Floating Beacons

Light Vessels or Floats



The Position of a Light Vessel, Buoy, or Beacon is the centre of the Base, and is usually indicated by a small circle.

B., Blk., *Black.*
Cheq., *Chequered.*
G., *Green.* Gy., *Gray.*
H.S., *Horizontal Stripes.*
N°., *Number.*
R., *Red.*
S.B., *Submarine Bell* (*sounded by wave action*).
S.F.B., *Submarine Fog Bell* (*mechanically sounded*).
V.S., *Vertical Stripes.*
Y., *Yellow.* W., Wh., *White.*

The Heights given against Beacons or marks forming beacons (such as Chimneys) represent the Height of the Top of the object above Mean High Water Spring Tides, or above the sea level where there is no tide.

Tides and Tidal Streams

H.W.F. & C. $IX^{h.}$ $25^{m.}$, *High Water Full and Change.* The hours are expressed in Roman figures, except $2^{h.}$

Equin$^{l.}$, *Equinoctial.*
Fl., fl., *Flood.*
*H.W., *High Water.*
†H.W.O.S., *High Water Ordinary Springs.*
h., *hour, hours.*
kn., *knot, knots.*
*L.W., *Low Water.*
†L.W.O.S., *Low Water Ordinary Springs.*
M.H.W.S., *Mean High Water Springs.*
M.L.W.S., *Mean Low Water Springs.*
m., *minutes.*
Np., *Neap Tides.*
†ord., *ordinary.*
$Q^{r.}$, *Quarter.*
Sp., Spr., *Spring Tides.*

} *Current.*

Flood Tide Stream.

Ebb Tide Stream.

The period of the tide at which the streams are running in the direction of the arrows is denoted as follows :—

(1) 1^{st} $Q^{r.}$, 2^{nd} $Q^{r.}$, etc. for the Quarters of each Tide — 2^{nd} $Q^{r.}$ 2^{nd} $Q^{r.}$

(2) $I^{h.}$, $II^{h.}$, $III^{h.}$, etc. for 1^{st}, 2^{nd}, 3^{rd} hours after High or Low Water — $II^{h.}$ $III^{h.}$

(3) Black dots on the arrows, the number of hours after High or Low Water (the reference being to High or Low Water in the locality, unless otherwise stated on the chart).

3 hours after High Water and 3 hours Ebb are both indicated by

4 hours after Low Water and 4 hours Flood are both indicated by

The Velocity of Currents and Tidal Streams is expressed in knots, thus :— 1 kn 5 kn

The Rise of Tide is given above the Datum of the chart.

The Datum to which soundings are reduced, unless otherwise stated, is approximately Mean Low Water of Spring Tides.

* H.W. or L.W. always refers to Mean High Water or Mean Low Water of Spring Tides, unless otherwise stated.

† These terms will not appear on new charts or new editions of charts published subsequent to June 1914.

(6) Lights and Light Lists

Light Systems.—Lights show either a continuous light of one colour or they may be varied by change of colour, flashes, eclipses, etc.

Abbreviations used in charts and Light Lists, and their meanings, are as follow :—

Alt., *Alternating*	*i.e.* A light that changes colour. This may be used in conjunction with any of the following systems.
F., *Fixed*	*i.e.* A continuous light.
Fl., *Flashing*	*i.e.* A light totally eclipsed at regular intervals, the duration of darkness being always greater than the duration of light.

These lights are of two kinds, viz. :

(*a*) Showing single flashes at regular intervals.
(*b*) Showing a steady light with total eclipses at regular intervals.

F. Fl., *Fixed and Flashing*	*i.e.* A continuous light varied at regular intervals by single flashes of greater brilliancy, which may or may not be followed by eclipses.
Gp. Fl., *Group Flashing*	*i.e.* A light showing groups of two or more flashes at regular intervals.
F. Gp. Fl., *Fixed and Group Flashing*	*i.e.* A continuous light varied at regular intervals by groups of two or more flashes.
Occ., *Occulting*	*i.e.* A light eclipsed at regular intervals, the duration of light being always greater than or equal to the duration of darkness.
Gp. Occ., *Group Occulting*	*i.e.* A continuous light varied at regular intervals by groups of two or more eclipses.
Rev., *Revolving*	*i.e.* A light gradually increasing to brightness and decreasing to darkness.
U., *Unwatched*	*i.e.* An unattended light ; such lights should not be implicitly relied on.
R., *Red* Gr., *Green* W., *White*	Referring to the colour of the light or the colour of the flashes shown. If no colour abbreviation is given, the light is white.

The Period of a light is the interval between successive commencements of the same cycle of changes.

Thus " ev. 3 mins." means, the cycle of changes shown against the light recommences every three minutes.

Gas Buoys are always flashing or occulting in order that they may not be mistaken for small vessels at anchor. Gas buoys should not be implicitly relied on, as bad weather may prevent their being recharged, or they may drift.

Light Lists

Admiralty Light Lists and correction of information, etc.

(1) Admiralty Light Lists are published annually on the 1st January. They are not corrected before issue.
(2) Appendices to Admiralty Light Lists are issued every two months, giving the changes that have taken place.
(3) Notices to Mariners of a later date than the last bi-monthly Appendix also correct the Light List.
(4) Notification should be made in the beginning of Admiralty Light Lists of Appendices and Notices to Mariners that correct the Light List.

Information in Light Lists.

(1) Useful information on Lights and Fog Signals is given at the beginning.
(2) A Table of Distances for various heights of eye is given at the end.
(3) **Bearing** given of Lights and their sectors is magnetic and is given from seaward. The variation of the year of issue of the List is used.
(4) **Colour** of Lighthouses and Light-ships is given, with details of each.
(5) **Height of top** of Daymark in Light-ships above the water line is given in Pt. I.
(6) **Power of a light** is given in units of 1000 candle-power.
(7) **Order of a light** refers to the diameter of the apparatus ; there are six orders.
(8) **Important lights** are printed in thick, large type.
(9) **The small letter** in brackets after a light indicates the authority responsible for its care and maintenance.
(10) **Light buoys** are not given in the Admiralty Light List.

(7) Sailing Directions

Correction of Information contained in Sailing Directions.

(1) Sailing Directions are not corrected before issue.
(2) In the advertisement at the beginning of the book is given the number of the last Notice to Mariners included in the original compilation.
(3) Supplements and Revised Supplements are published as necessary.
(4) Revised Supplements cancel previous Supplements.
(5) In the Advertisement at the beginning of a Supplement or Revised Supplement, the number of the last included Notice to Mariners is given.
(6) Notices to Mariners also correct Sailing Directions; these should be pasted in the Sailing Directions in their appropriate place.
(7) Notices to Mariners, Supplements, and Revised Supplements affecting Sailing Directions should be noted in page iii of Advertisement to Sailing Directions.
(8) A Summary of the information in Notices to Mariners affecting a volume of Sailing Directions is issued in January of each year for conveniently pasting in. This is not issued if a Supplement or Revised Supplement is in course of preparation.
(9) Notices to Mariners, Supplements, and Revised Supplements should be in duplicate, one copy to cut up and paste in in appropriate places, the other copy to retain intact for future reference.

Useful Information in Sailing Directions, and Notes thereon

Note (1).—Where the information in Sailing Directions differs from that on large-scale Charts or in Light Lists, the Chart or Light List should be relied on, especially if the two latter are of more recent date. Sailing Directions are frequently incorrect in minor details and in arrears in corrections already on the Charts and in Light Lists.

Note (2).—Bearings given are magnetic. The Variation used and the date of this Variation are given at the head of each chapter; in later editions these are given in the margin.

Note (3).—For additional information *re* Lighthouses and Lightships not given on charts, consult the Light Lists.

Sailing Directions should always be consulted, *especially before anchoring in any strange anchorage*, and for the following information, viz. :—

(1) Signals indicating that ports are closed during hostilities, or that the Examination Service is in operation, and directions as to procedure.

(2) Appearance of Land, Daymarks, Lighthouses, Light-ships, etc. These sketches are of great value when making the land.
(3) Colour and description of Lighthouses, Light-ships, etc., the arcs lights show over, bearings and dangers indicated.
(4) Coastwise dangers, rocks, outlying shoals, with bearings or leading marks for avoiding the same.
(5) Signal Stations and local weather signals.
(6) Signals indicating depths of water on bars at harbour entrances.
(7) Local tides, currents, freshets, etc.
(8) Buoys and buoyage systems, leading marks, etc.
(9) Anchorages, nature of holding ground, danger from gales, etc. ; this information should always be read before anchoring in open or exposed roadsteads.
(10) Mooring and mooring buoys, and size of ship for which such are available.
(11) Quarantine grounds and anchorages.
(12) Landing-places, water supply, and other local information.

(8) Winds and Storms

Weather wisdom is essentially the outcome of practical experience, but the Laws of Winds and Storms from scientific investigation are here briefly explained.

The seasons, regions, and extent of calms, prevailing winds, and storms are not given, as full information of these is contained in the publications below enumerated. These publications should always be consulted instead of trusting to memory or to a condensed summary of the information contained therein.

(*a*) For calms, prevailing winds, storms, and ocean currents—Consult the " Wind and Current Charts." These give the seasons, regions, and extent of above at all times of the year, and the storm seasons.

(*b*) For wind and weather near coast, and storm signals—Consult the " Sailing Directions."

(*c*) For mean barometric pressure in January and July—Consult the " Barometer Manual " ; this should be carefully studied when in the tropics or when in storm regions.

(*d*) For suitable ocean passages—Consult the volume of " Ocean Passages " and the " Pilot Charts," especially the American " Pilot Charts," published monthly.

Definitions and Laws of Wind System

Wind is said to " Veer " when it " shifts," *i.e.* changes its direction, Clockwise.

Wind is said to " Back " when it " shifts," *i.e.* changes its direction, Anticlockwise.

Cyclonic winds or Cyclonic systems are winds blowing round a centre of Low pressure.

Anticyclonic winds or Anticyclonic systems are winds blowing round a centre of High pressure.

North of the Equator, Cyclonic winds blow Anticlockwise round the centre.

,, ,, ,, Anticyclonic winds blow Clockwise round the centre.

South of the Equator, Cyclonic winds blow Clockwise round the centre.

,, ,, ,, Anticyclonic winds blow Anticlockwise round the centre.

Cyclonic Systems usually bring strong winds and bad weather, and move rapidly.

Anticyclonic Systems usually bring light winds and fine weather, and move slowly or are nearly stationary.

Cyclonic and Anticyclonic Systems in temperate regions, *i.e.* North of 30° N. or South of 27° S., almost invariably travel to the *Eastward*, or in the Northern Hemisphere to the N.E., and in the Southern Hemisphere to the S.E.

Cyclones, the revolving storms of tropical regions, travel to the *Westward* between 30° N. and 27° S., curving towards the Pole of their respective hemisphere and moving nearly due North in 30° N. and nearly due South in 30° S., thence curving to the N.E. and S.E. respectively.

Conclusions to be drawn from Changes in the Direction of the Wind

In the temperate regions of both hemispheres, where *Cyclonic* systems move to the Eastward, if the observer is stationary, then—

The wind "Veers"	in N. Hemisphere from S. through W. to N. ,, S. ,, ,, N. ,, E. ,, S.	when the cyclonic centre is *North* of the observer.
The wind "Backs"	,, N. ,, ,, S. ,, E. ,, N. ,, S. ,, ,, N. ,, W. ,, S.	when the cyclonic centre is *South* of the observer.

The above is a rough probable change in the direction of the wind before the weather clears up.

In Anticyclonic systems, and in Revolving Storms in the tropics moving to the Westward, the reverse to the above holds true.

Conclusions to be drawn from Barometric Readings

The violence of the wind in Cyclonic or Anticyclonic systems generally depends on the closeness of the "*Isobars*" or curves of equal barometric pressure.

Generally, the closer the Isobars the more violent is the wind.

The distance apart of Isobars can only be determined by simultaneous observations at various stations, allowance being made for the rate of progression of the system.

To a single observer a rapid barometric *fall* or *rise* indicates the Isobars are close, though this conclusion is greatly modified by—

(*a*) The rate at which the wind system is moving to or from him.

(*b*) The rate at which an observer in a ship may be moving to or from the wind system.

(*c*) A large general fall over surrounding areas when strong winds may not occur with a Cyclonic system.

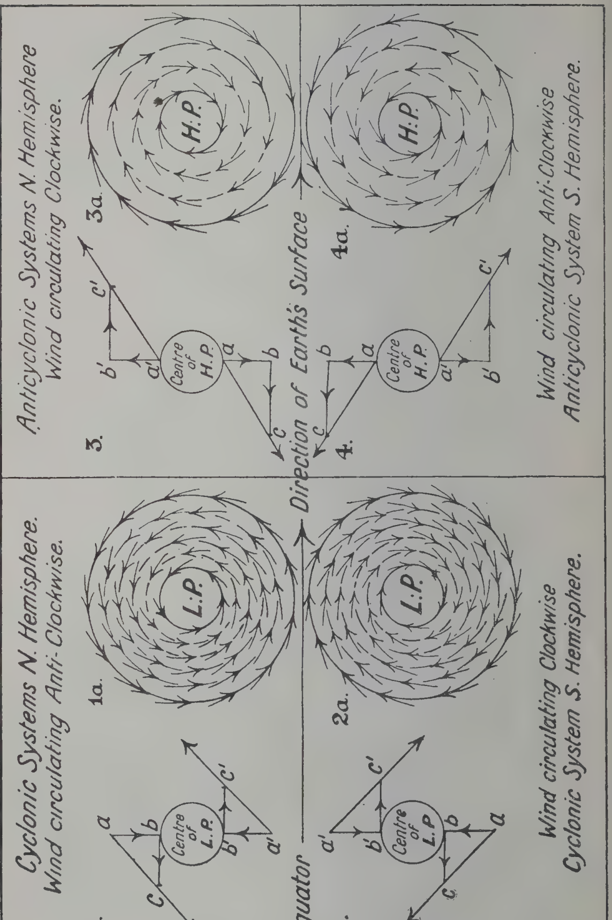
(*d*) Conversely, in an Anticyclonic system strong winds may occur owing to large barometric falls in surrounding areas.

Note.—To a single observer the closeness of Isobars is best observed by the sharpness of the rising or falling curves in *recording* aneroid barometers.

Explanation of Wind Systems

Air when heated becomes lighter, it rises, and consequently the pressure decreases; to preserve equilibrium, cooler air from around flows in.

[To face p. 53.


Cyclonic Systems N. Hemisphere.
Wind circulating Anti-Clockwise.
Anticyclonic Systems N. Hemisphere
Wind circulating Clockwise.
1.
1a.
3.
3a.
Equator
Direction of Earth's Surface
2.
2a.
4.
4a.
Centre of L.P.
Centre of H.P.
L.P.
H.P.
Wind circulating Clockwise
Cyclonic System S. Hemisphere.
Wind circulating Anti-Clockwise
Anticyclonic System S. Hemisphere.

Now wind from the N. or S. blowing from higher to lower latitudes has also the speed, from W. to E., at the higher latitude of the earth's surface.

The speed of the earth's surface to the E. is greater in low than in higher latitudes. Therefore, just as the wind appears to draw ahead when a ship with wind abeam increases speed, so N. or S. winds from higher to lower latitudes will appear to come from the Eastward of N. or S.

This is seen in the Trade Winds. They are N.E. in Northern and S.E. in Southern Hemisphere.

These Trades Wind are also more N. or S. when strong and more E. when weak.

Conversely, wind from the N. or S. blowing from lower to higher latitudes has also the speed, from W. to E., at the lower latitude of the earth's surface.

The speed of the earth's surface to the E. is less in high than in lower latitudes. Therefore, just as the wind appears to draw astern when a ship with wind abeam decreases speed, so N. or S. winds from lower to higher latitudes will appear to come from the Westward of N. or S.

This is seen in the S.W. monsoons of the Gulf of Guinea, Indian Ocean, and China Sea, and the N.W. monsoon of the South Indian Ocean.

These Monsoons, like the Trades, are more N. or S. when strong and more E. when weak.

From the foregoing conclusions the reason for the directions that winds blow round Cyclonic or Anticyclonic systems North or South of the Equator can be deduced.

Thus, in diagrams 1 and 2—

If *ab*, *ab* are the original directions of the wind from high latitudes, and *a′b′*, *a′b′* are the original directions of the wind from low latitudes;

If *bc*, *bc* is the relative earth motion in a lower latitude, and *b′c′*, *b′c′* is the relative earth motion in a higher latitude;

Then *ac*, *ac* are the resultant wind velocities in lower latitudes, and *a′c′*, *a′c′* are the resultant wind velocities in higher latitudes.

Hence in the case of an area of low pressure N. of the Equator (diagram 1) a Northerly wind becomes North-easterly and a Southerly wind becomes South-westerly, and the wind circulates anticlockwise (diagram 1*a*).

And in the case of an area of low pressure S. of the Equator (diagram 2) a Northerly wind becomes North-westerly and a Southerly wind becomes South-easterly, and the wind circulates anticlockwise (diagram 2*a*).

In Anticyclonic Systems or areas of high pressure the reverse to the above holds true (*v.* diagrams 3 and 4), thus :—

North of the Equator in an Anticylonic system the wind circulates Anticlockwise (*v.* diagram 3*a*).

South of the Equator in an Anticyclonic system the wind circulates Clockwise (*v.* diagram 4*a*).

In the accompanying diagrams the " Isobars " or lines of equal barometric pressure are represented by circles ; they are, however, generally irregular or oval in form, except in the so-called " Revolving Storms " of tropical and subtropical regions, where they are more nearly circular.

The direction of the wind approximates more nearly to the tangent to the Isobar nearer the centre, and generally cuts the Isobars at an angle of 20° to 40° inclining to the centre as shown.

Hence Buys-Ballot's Law can be deduced, and may be stated thus :—

" Face the wind.

" N. of the Equator the centre of low pressure is about 110° to the Right.

" S. of the Equator the centre of low pressure is about 110° to the Left."

Note.—The bearing of the centre will only be at 110° after a decided fall of the barometer. In the earlier stages of an approaching storm the bearing of the centre should be taken above as 130°.

Remarks on Wind Systems

In latitudes 30° N. and 30° S. a constant high pressure generally exists which causes the prevailing Westerly winds so common in higher latitudes about 40° N. or S.

These zones of Westerly winds are called " Horse Latitudes " in the Northern and " Roaring Forties " in the Southern Hemisphere.

In the latter (" Roaring Forties ") the wind being unobstructed by land blows almost incessantly round the world, causing a heavy sea.

In the temperate zones Cyclonic Systems travel to the E., as seen in the gales coming to the British Isles and W. coast of Europe from Canada, N. America, and the Gulf of Mexico. These gales travel rapidly and generally disperse over the continent.

From the diagrams 1*a* and 2*a* it will be seen that, in the temperate regions in both hemispheres where Cyclonic Systems move to the Eastward, if the observer is stationary—

The wind *" Veers "*	in N. Hemisphere from about	S.W. through	W. to	N.W.	If the cyclonic centre is N. of the observer.
	,, S. ,, ,,	N.E. ,,	E. ,,	S.E.	
The wind *" Backs "*	,, N. ,, ,,	S.E. ,,	E. ,,	N.E.	If the cyclonic centre is S. of the observer.
	,, S. ,, ,,	N.W. ,,	W. ,,	S.W.	

when the weather in each case may be expected to clear up, unless another cyclonic system is following the former—a frequent occurrence.

Storm Signals are given in the Sailing Directions.

In the British Isles a Storm Cone, black, is hoisted when a storm is expected.

At places S. of probable path of storm, cone is point down and called a "South Cone."

At places N. of probable path of storm, cone is point up and called a "North Cone."

In Anticyclonic Systems moving to the E. the wind will shift to a stationary observer in a direction the reverse to that above for Cyclonic Systems:

i.e. The wind "Backs" if the Anticyclonic Centre is N. of the observer.

The wind "Veers" if the Anticyclonic Centre is S. of the observer.

Anticyclonic Systems move slowly and are often stationary for days, with a calm in the centre and light winds on the outskirts; they frequently cause fogs.

Land and Sea Breezes are very prevalent in the summer and in the tropics.

During the day the land heats quicker than the sea, and "Sea Breezes" blow in from seaward, dying away towards evening.

During the night the sea retains the heat of the day, while the land cools rapidly, and "Land Breezes" blow out from the land seawards, dying away towards morning.

Land and Sea Breezes are very common and regular in the West Indies and tropics.

The Monsoons are Land Breezes due to the low pressure established over the Sahara, India, and China by the heat of the summer, so causing the S.W. Monsoon over the Gulf of Guinea, Indian Ocean, and China Seas respectively during the greater part of the summer.

Around Australia similar phenomena occur, thus:—

In summer, low pressure causes a Cyclonic System, and winds circulate round continent Clockwise.

In winter, high pressure causes an Anticyclonic System, and winds circulate round continent Anticlockwise.

The Trade Winds caused by permanent low pressure at the Equator blow N.E. North of Equator and S.E. South of Equator, as already shown.

Beaufort Notation

To indicate Force of Wind and State of Weather

Wind

Notation.	Denoting	Approx. miles per hr.	Corresponding ft. per min.	Corresponding pressure, lbs. per sq. in.
0	Calm . .	0	0	·0
1	Light Airs .	1	88	·005
2	Light Breeze .	2 to 3	176 to 264	·020 to ·044
3	Gentle ,, .	4	352	·079
4	Moderate ,, .	5	440	·123
5	Fresh ,, .	10	880	·492
6	Strong ,, .	15	1320	1·107
7	Moderate Gale	20 to 25	1760 to 2200	1·970 to 3·067
8	Fresh ,,	30 ,, 35	2640 ,, 3080	4·429 ,, 6·029
9	Strong ,,	40 ,, 45	3520 ,, 3960	7·870 ,, 9·900
10	Whole ,,	50	4400	12·364
11	Storm . .	60 to 70	5280 to 6160	17·738 to 24·153
12	Hurricane .	80 ,, 100	7040 ,, 8800	31·490 ,, 49·200

Weather

b=Blue sky.
c=Clouds, detached.
d=Drizzling rain.
f=Foggy.
g=Gloomy.
h=Hail.
l=Lightning.
m=Misty.
o=Overcast.
p=Passing showers.
q=Squally.
r=Rain.
s=Snow.
t=Thunder.
u=Ugly, threatening.
v=Visibility (distance at which objects are seen).
w=Dew.

A bar under any letter augments its signification, thus :—

$\underline{\text{r}}$=Heavy rain. $\underline{\underline{\text{r}}}$=Very heavy rain.

Storms in Tropical and Subtropical Regions

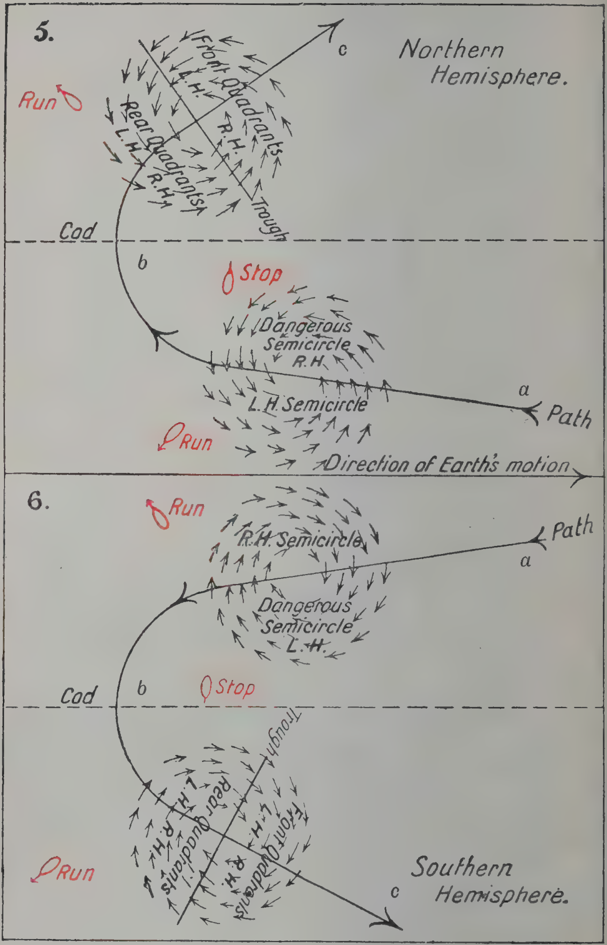
In certain localities, within the tropics, centres of low pressures give rise to severe storms, popularly called "Revolving Storms."

These storms have different names in different localities, but they may correctly be termed "Cyclones," being cyclonic in character, and differing from cyclones in other parts of the world only in their curved path and intensity.

As in other cyclonic systems, the wind in these storms circulates round the centre—Anticlockwise in the Northern and Clockwise in the Southern Hemispheres respectively.

The peculiar characteristics of these storms are that they :—

(1) Usually commence not less than 5° or 6° N. or S. of the Equator.


5.
Northern Hemisphere.
Run
Front Quadrants
L.H.
R.H.
Rear Quadrants
L.H.
R.H.
Trough
c
Cod
b
Stop
Dangerous Semicircle R.H.
L.H. Semicircle
a
Path
Run
Direction of Earth's motion
6.
Run
R.H. Semicircle
Path
a
Dangerous Semicircle L.H.
Cod
b
Stop
Trough
Rear Quadrants
L.H.
R.H.
Front Quadrants
L.H.
R.H.
Run
Southern Hemisphere.
c

(2) Travel at first to the Westward, inclining always towards the Pole of the hemisphere in which originated.
(3) Curve round in about 30° N. or 25° S. to the Pole of the hemisphere in which originated, and then travel to the North-eastward in the Northern or South-eastward in the Southern Hemispheres respectively, finally dispersing.
(4) Are repelled generally by the land, as in the West Indies and North and South Pacific.
(5) Pursue occasionally a straight course, sweeping over the land without curving, but inclining to the Pole of the hemisphere they are in. This occurs sometimes in the Cyclones of the Gulf of Mexico, Bay of Bengal, and China Seas.
(6) Increase greatly in violence towards the centre of the storm, where a sudden drop of wind may occur, though with rapid changes of wind often coming suddenly from the opposite quarter with great violence, with a confused and dangerous sea.

Diagrams 5 and 6 are typical of the paths followed by these storms in the N. and S. Hemispheres.

Definitions

The Path of the Storm is the track *a*, *b*, *c*, followed by the centre of low pressure.

The Cod of the Storm is the point of curvature furthest W. (about 30° N. or 25° S.).

The Right-hand Semicircle is that on the right of the path facing the direction of advance.

The Left-hand Semicircle is that on the left of the path facing the direction of advance.

The Right-hand Semicircle is the *dangerous* semicircle in the Northern Hemisphere.

The Left-hand Semicircle is the *dangerous* semicircle in the Southern Hemisphere.

These semicircles are called " dangerous " because they lie within the curvature of the path of the storm, and sailing ships in the " dangerous semicircle " are liable to be blown across the path of the storm.

The Trough of the Storm is the line through the centre of the storm at right angles to the path.

The Trough divides each semicircle into the " Front " and " Rear " Quadrants.

The Right Front Quadrant is the most dangerous in the Northern Hemisphere.

The Left Front Quadrant is the most dangerous in the Southern Hemisphere.

Approximate Summary of Revolving Storms, Seasons, etc.

Northern Hemisphere

Locality.	Approx. origin.	Approx. lat. of Cod.	Season.	Name.	Average daily travel.
					Miles.
West Indies .	10° to 13° N.	30° N.	July to Oct.	Hurricane.	300
North Pacific	20° N., near Ladrone Islands.	27° N.	Do.	Do.	..
China Sea .	Luzon and Palawan Islands.	27° N.	July to Nov.	Typhoon.	200
Bay of Bengal	Andaman Islands.	..	Apr. and May and Oct. and Nov.	Cyclone.	200
Arabian Sea .	Laccadive Islands.	..		Cyclone.	200

Southern Hemisphere.

Locality.	Approx. origin.	Approx. lat. of Cod.	Season.	Name.	Average daily travel.
South Indian Ocean .	10° S., and near Lunda Islands.	26° S.	Dec. to Apr.	Cyclone.	50 to 200
South Pacific .	Near Ellice and Solomon Islands.	15° S.	Do.	Hurricane.	..

Indications of Revolving Storms, and Measures to take for avoiding the same

The indications of Cyclones, Hurricanes, and Typhoons are :—

(1) Confused and troubled sea.
(2) Ugly, threatening sky.
(3) Fall in the barometer or a change in the diurnal variation.

The Barometer.—Owing to the small but regular diurnal variation of the barometer in the tropics, any irregularity or interruption of these changes is a very sure indication of atmospheric disturbance.

When in storm regions, therefore, the barometer should be watched attentively and the Barometer Manual studied.

A self-recording aneroid barometer is a most valuable instrument for indicating changes, and giving warning of atmospheric disturbances.

The Diurnal Variation may be summarised as follows :—

(1) Is seldom more than ·1 inch.
(2) The Maximum daily readings are, rather before 10 A.M. and rather after 10 P.M. The 10 A.M. maximum is the greater.
(3) The Minimum daily readings are at about 4 A.M. and 4 P.M. The 4 P.M. minimum is the lesser.

If these changes are interrupted or if a sudden fall occurs, an atmospheric disturbance may be expected.

The following procedure is recommended when these storms are expected:—

(1) Ascertain the relative position of the storm to the ship, thus:

(*a*) Stop the ship.
(*b*) Watch the barometric changes.
(*c*) Watch the direction in which the wind shifts.

(2) Ascertain the bearing of the centre of the storm, thus:

Face the wind—then by Buys-Ballot's law—

North of the Equator, centre is 10 points to the Right.
South ,, ,, ,, 10 ,, ,, Left.

Note.—This law will not hold true until there has been a decided barometric fall of, say, ·5 inch. With lesser fall of barometer the bearing should be taken as 12 points instead of 10.

(3) Ascertain which Semicircle the ship is in, thus:

Face the wind—then in *both* hemispheres—

In Right-hand Semicircle wind Veers.
In Left-hand ,, ,, Backs.

If in the "Dangerous Semicircle," Right (N. of Equator): Left (S. of Equator)—

In a steamship *Stop*; in a sailing ship "*Heave to,*" thus:

Heave to on Starboard Tack in Northern Hemisphere.
,, ,, Port ,, Southern ,,

If in the "Safe Semicircle," Left (N. of Equator): Right (S. of Equator)—

"Run" with wind on Starboard Quarter in Northern Hemisphere.
"Run" with wind on Port Quarter in Southern Hemisphere.

(4) Ascertain which Quadrant ship is in, thus:

Barometer falls when in Front Quadrants.
,, rises ,, Rear ,,

(5) Ascertain if ship is in the Path of the Storm.

If in Path of Storm, wind should remain almost constant in direction, increasing in violence, with the barometer falling rapidly. In this case—

Run with wind on Starboard Quarter in Northern Hemisphere.
,, ,, Port ,, Southern ,,

Particular Characteristics of South Indian Cyclones

(1) Buys-Ballot's law cannot be applied until the wind has shifted decidedly to the S. or E.

(2) The strong south-easterly trade may frequently be mistaken for a coming storm, and the mariner should be on guard against this error.

(3) Special caution is necessary as strong N.E. and E. winds frequently, if not always, blow directly to the centre of these cyclones.

(4) In these cyclones, if the wind shifts directly from S.E. to E., run to the N.W.

(5) If the wind remains steady at S.E. and the barometer falls, the ship is in the path of the storm and should run to the N.W.

SECTION (a)

Channel Navigation

Channel Navigation comprises the navigation of Estuaries, Rivers, Harbours, with their approaches, and the navigation of narrow channels with banks, shoals, or other dangers on both sides.

The duties of the navigator are :—

(*a*) To select the most convenient channel to use and determine on the various turning points.

(*b*) To ascertain whether the depth of water is sufficient in the whole length of the channel.

(*c*) To determine whether the channel is sufficiently clearly indicated for safe navigation.

The navigable channels of estuaries, harbours, etc., are marked in three ways :—

(*a*) By Leading Marks.

(*b*) By True and Magnetic Bearings of well-defined objects.

(*c*) By Buoys, Beacons, Daymarks, Lights, etc.

(*d*) By various combinations of the above.

Before entering an estuary or harbour for the first time, it is desirable to determine beforehand, for the speed at which the ship will proceed :—

(1) The various Compass Courses to steer.

(2) The Run or Time on each course, allowing for turns.

(It is generally easier to enter at slack water, but if this cannot be done, allowance for Set and Drift of the Tidal Stream or Current must be made.)

Previously prepared data, such as are indicated further on, should be invaluable when entering in foggy or misty weather ; for the navigator is thereby enabled to direct his whole attention to conning the ship, noting the soundings, and generally keeping a good look-out ; and his attention is not diverted by referring to charts, laying off courses, etc.

On entering or leaving estuaries, harbours, etc., an assistant should always check the Courses and Runs computed by those actually steered, and correct any errors in the former. In this manner useful records are obtained, for future reference, that should be of great value and give confidence when entering in thick or foggy weather, or when entering badly lit ports at night.

As examples :—When making a night attack on Berehaven, ship darkened, chart-house and chart-table lights out, and only sufficient light in the steering compass for the helmsman, a

record of courses, with the time on each, was relied on solely for entering. An assistant with a watch and the computed record gave the courses to steer and the instants at which to put the helm over. No reference was made to the chart, nor were any bearings of the lighthouse or land taken.

Again—When entering Firth of Tay in a fog, a record was relied on; the channel buoys were not seen till almost abeam within a few seconds of the scheduled times.

A suggested more convenient form, than the ship's log book, for keeping these records is shown in the facsimile of the Dead Reckoning Book.

The facsimile of the Dead Reckoning Book given shows a record for entering Harwich Harbour at slack water at a speed of 10 knots. The "Advance," *i.e.* the distance the ship travels along her original course between the moment of commencing to put the helm over and the moment of commencing to turn, is, at the speed of 10 knots, taken as 100 yards.

From Cork Light Vessel to Harwich Coast Guard Buoy. Date 9th July 1914. Time of H.W. at Dover, A.M. 8 *hrs.* 31 *mins.*, P.M. 9 *hrs.* 2 *mins. Draught Forward, 27 ft. 6 ins.; Aft., 29 ft. 0 ins.*

From	To	Distance.	Patent log.	Total revs.	Course magnetic.	Speed.	Current.		Course steered.	Speed made good.	Time.		Remarks and Fixes.
							Set.	Drift.			Intervals.	Clock.	
		Naut. miles.							Dev.		h. m. s.	h. m. s.	
Cork Lt. V., 185°, 1 cable	Felixstowe Pier, 35·6°	·57		228	275·5				1° E. = 274·5		0 3 16	9 30 0	Cork Lt. Vessel, 185°, 1 cable.
H_1	H_2	·58		232	251·5				1° E. = 250·5		0 3 19	9 33 16	Felixstowe Pier, 35·6°.
H_2	H_3	·31		124	289				0 = 289		0 1 46	9 36 35	„ „ 17·5°.
H_3	H_4	·54		216	278	10·5	Slack	Water	0 = 278	10·5 kns.	0 3 05	9 38 21	„ „ 37°.
H_4	H_5	·27		108	282·5				0 = 282·5		0 1 32	9 41 26	Landguard Lt. Ho. Occ., 2°; Lights in line, 282°·5.
H_5	H_6	1·1		440	27				1° W. = 28		0 6 17	9 42 58	Landguard Lt. Ho. Occ., 28°; Lights in line, 27°.
H_6	Coast Guard Buoy abeam	·92		368	316				1·5° W. = 317·5		0 5 15	9 49 15	High Lt., Red, 108°; Lights in line, 136°·5
	Total .	4·29		1716							0 24 30		9h. 54m. 30s., Coast Guard Buoy abeam.

Making and Checking a Record for Channel Navigation in the Dead Reckoning Book

On the Left-hand page fill in as follows :—

Column.

1 and 2. Names, in consecutive order, of Points, Buoys, etc., at which course is altered.

3. Distance in cables between the objects in Columns 1 and 2, less the " Advance."

Note.—The advance must be laid off from the object in column 2, in the direction from which the ship is approaching.

4. Fill in before or while entering.

6. Magnetic Course from the object in Column 1 to that in Column 2.

Note.—Correct the Magnetic Compass on the Chart for the annual change of variation.

7. The Speed at which the ship will proceed.

8 and 9. The Tidal Set and Drift when entering.

Note.—Tidal Set and Drift can be taken from the Chart, Sailing Directions, or at light-ships from the Light Lists.

On the Right-hand page fill in as follows :—

Column.

1. Compass Course to steer, *i.e.* the Magnetic Course in Column 6 corrected for Set and Drift of Tidal Stream and the Deviation.

2. The Speed, Column 7 left-hand page, corrected for Set and Drift.

3. The Time on each Course. Divide the Distance in Column 3 left-hand page by the Speed in Column 2 right-hand page, and divide the result by 10.

4. This should be filled in when entering or leaving, by an assistant, with the exact times at which the objects Columns 1 and 2 are passed, and afterwards compared with the computed time-intervals.

The Remarks Column may be used for notes as to Transits, Bearings of Leading Marks, Buoys, etc. If soundings between the turning points are inserted, they should be a useful guide in foggy weather.

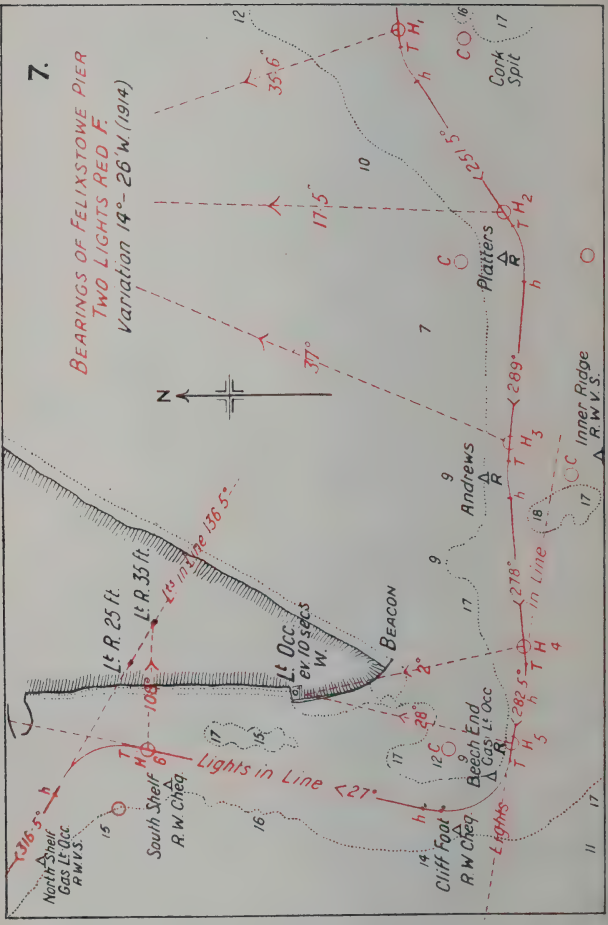
Laying off a Channel Track on a Chart

A further useful and instructive precaution, before entering a narrow channel or strange harbour for the first time, is to lay off carefully on the chart the track it is intended to pursue.

For example :—

(1) Lay off the track determined on, marking against each run the Compass Course to steer.

(2) Lay off at each turning point (with radius representing the tactical radius for the speed) the turning arc described by the ship.


7.
BEARINGS OF FELIXSTOWE PIER
TWO LIGHTS RED F.
Variation 14° - 26' W. (1914)
N
Lt R. 25 ft.
Lt R. 35 ft.
Lts in Line 136.5°
Lt Occ. ev. 10 secs W.
BEACON
Lights in Line 27°
108°
28°
2°
37°
17.5°
35.6°
316.5°
282.5°
278°
289°
251.5°
in Line
Lights
North Shelf Gas Lt Occ. R.W.V.S.
South Shelf R.W. Cheq.
Cliff Foot R.W. Cheq.
Beech End Gas Lt Occ R.
Andrews R
Platters R
Inner Ridge R.W.V.S.
Cork Spit
TH1
TH2
TH3
TH4
TH5
TH6

(3) Mark the points at which the helm should commence to go over, allowing for the "Advance."

(4) Mark the Transits or Bearings giving the points at which the helm should commence to go over. These Transits or Bearings should be selected so as to be as nearly as possible at right angles to the Track.

Note (1).—A common mistake is that of putting the helm over too late. This should not occur if it is remembered that when the helm is put over too soon it can be quickly eased, but when it is put over too late (in cases where full helm has been allowed for) more helm cannot be given.

Note (2).—That point in a ship which travels along the turning arc marked on the chart, is generally at the centre of the fore bridge. This should be remembered in a long ship, that care may be taken not to swing the stern too near a danger.

A facsimile of the Channel Track for Harwich Harbour is shown in diagram 7.

The Bearings are Magnetic for 1914. Variation 14° 20′ W.

H, H, H mark the points where the helm is put over on entering the harbour.

h, h, h mark the points where the helm is put over on leaving the harbour.

T, T, T mark the points where the ship commences to turn on entering the harbour.

HT is the advance on entering the harbour.

C, C, C are the centres of the turning circles.

Note.—In daytime it might be considered more convenient to use bearings of the Beacon on Landguard Point. Bearings of the Lighthouse are, however, given, as it is desirable, by day, to use bearings of lights that must necessarily be used at night.

(1) Leading Marks

Leading Marks are two natural or artificial objects which, when in line, point the navigable channel. These are preferable to any other means of marking a channel providing :—

(*a*) It is clear weather.
(*b*) That the marks are conspicuous.
(*c*) That the marks are sufficiently far apart to "open" directly the ship is off their line of coincidence.

The lower mark is the nearer, or should be so selected.

The distance apart of Leading Marks should be looked to, to ensure that they give a reliable line. As a rough guide, their distance apart should not be less than $\frac{1}{5}$th of the greatest distance at which they are used.

Always take the bearing of Leading Marks when in line, to ensure that the correct objects are used.

The navigator must accustom himself to give the correct order for the helm immediately the marks are out of alignment, thus :—

Lower or nearer	to Right of	Upper or further	If marks are ahead, order Port Helm. If marks are astern, order Starboard Helm.
Lower or nearer	to Left of	Upper or further	If marks are ahead, order Starboard Helm. If marks are astern, order Port Helm.

(2) Leading Bearings

Bearings of some conspicuous object are sometimes given as the line marking the navigable channel.

Bearings should be used with great caution.

The object used should be close and conspicuous.

The navigator should lay off the bearing of the object with an error of two or more degrees on either side, and ascertain if such possible errors would place him in dangerous proximity to a shoal.

If the Magnetic Bearing is given it must be corrected for Deviation.

The navigator must accustom himself to give the correct order for the helm immediately the ship is off the correct bearing, thus :—

Object to Right of Bearing.	If object is ahead, order Port Helm. If object is astern, order Starboard Helm.
Object to Left of Bearing.	If object is ahead, order Starboard Helm. If object is astern, order Port Helm.

Notes on Leading Marks and Leading Bearings

(1) Leading Marks and Leading Bearings on a chart are shown with a line drawn through or to them, indicating the channel they lead through.

(2) This line (1) is solid or duplicate where the channel lies, and elsewhere dotted to guide the eye to the objects used. Thus, the line is dotted over land, shoals, or beyond a turning point.

(3) The names of the objects and their True and Magnetic Bearing, when marking the channel, are printed against the line.

(4) The Magnetic Bearing given is only correct for the Variation for the year as given on the chart; the annual change of Variation must be allowed for.

(5) In a cross tide, where Leading Marks or Leading Bearings cannot be kept ahead, the helmsman can keep a correct course by keeping the marks in line with some object in the fore part of the ship, such as a stanchion, thus allowing for the tide.

(6) In turning to bring Leading Marks in line, or to get on a Leading Bearing, the helm should be put over in good time. A common mistake is that of putting the helm over too late. This should not occur if it is remembered that when the helm is put over too soon it can be quickly eased, but when it is put over too late (in cases where full helm has been allowed for) more helm cannot be given.

(3) Buoyed and Beacon-marked Channels

In thick or foggy weather, when Leading Marks or Bearings are difficult to distinguish, buoyed or beacon-marked channels are easiest to enter. Buoys are also necessary to mark shoals and channels too far from land to be otherwise indicated.

The navigator is warned not to trust implicitly to buoys; their position may vary with the height of tide, they may drag or break away.

When entering a buoyed or beacon-marked channel in thick or foggy weather, if the visibility can be estimated, it is a good plan to put a visibility circle round each buoy or mark; then, if the buoy or mark is not seen when the ship should be in the visibility circle, it may be wise to anchor. The visibility may be estimated if the outer channel buoy is viewed by noting how long before the latter disappears.

Rounding a buoy is turning towards the side on which the buoy is passed.

Turning on a buoy is turning to the opposite side from that on which the buoy is passed.

In Rounding or Turning on a buoy, always put the helm over in good time, especially in the latter case, to avoid, in narrow channels, swinging the ship's stern on to the buoy.

Set and Drift of the current may be well estimated when passing buoys.

Buoyage Systems and Channel Marks

Shapes—Conical Buoys show the sharp point of a cone.
Nun ,, are the same as Conical Buoys, only smaller.
Can ,, show a flat top.
Spar ,, ,, a mast or spar.
Spherical ,, ,, a domed top.
Barrel ,, ,, an arched top.
Beacon ,, are buoys surmounted by a central beacon-shaped structure, such as Bell Buoys, Whistle Buoys, Gas Buoys, etc.

Beacons are marks fixed on the bottom, such as Dolphins, Piles, Stakes, Perches, and Trechen, etc. Trechen are small trees with or without their branches.

Abbreviations employed in charts and in the following remarks are:—

Colours—B., Blk. = Black.
G. = Green.
R. = Red.
W., Wh. = White.
Y. = Yellow.

Pattern—Cheq. = Chequered
S. = Stripes.
H.S. = Horizontal Stripes.
V.S. = Vertical Stripes.

If a colour letter only is given, the buoy is of the single colour indicated, except where a number, name, or letter is painted on to distinguish the buoy.

Numbers, names, and letters on Red, Green, or Black buoys are generally painted in White; on White buoys, in Black; and on Chequered or Striped buoys, White on the colour ground, and the colour of the buoy on the white ground.

Numbering almost invariably commences from seaward, Port hand buoys being odd numbered and Starboard hand buoys even numbered.

Note.—The Mersey buoys are an exception.

Port Hand Buoys are those marking the Left-hand side of the channel when entering from seaward, or going in the direction of the main stream of flood.

Starboard Hand Buoys are those marking the Right-hand side of the channel when entering from seaward, or going in the direction of the main stream of flood.

Middle Ground Buoys are those that mark shoals in the centre of a channel, where there is a passage on either side.

Outer Ends of Middle Grounds are the ends of shoals nearer seaward.

Inner Ends of Middle Grounds are the ends of shoals further from seaward.

Mid-Channel Buoys are those that mark the centre of a channel, and should be passed close to on their right hand side.

Isolated Danger Marks are marks placed on rocks or banks of small extent around which vessels can navigate.

Watch Buoys are buoys placed near light-ships that are too far from shore to verify their position by bearings. These are usually "Can" buoys painted Black, with "Watch" painted on them in White.

Submarine Telegraph Buoys mark the shore ends of submarine telegraph cables. These are painted Green, with "T," "Telegraph," or "Telegrapho," etc., painted thereon in White.

Submarine Mining Buoys mark the extent of mining fields, etc., and are Green with White Horizontal Stripes.

Germany.—Target, Mine, and Torpedo Grounds—Barrel Buoys, Yellow with a Red Flag. Quarantine Ground Buoys—Can, Conical, or Barrel painted Yellow.

Wreck Marking Buoys are Green, with "Wreck," "Wrack," or "Naufragée," etc., painted thereon in White. United States of America—Black and Red Horizontal Stripes.

Wreck Marking Vessels have their top sides painted Green, with "Wreck," "Naufragée," etc., painted thereon in white. They also carry—

By Day, three balls on a yard, two being vertical on the channel side.

By Night, three lights on a yard, two being vertical on the channel side.

Middle Grounds, Mid-Channel Marks, Isolated Dangers.

	Port Hand.	*Outer Ends.*	*Inner Ends.*	*Starboard Hand.*		*Remarks.*
England.						
Shape and colour.	Can, cheq.	Spherical, W.H.S.	Spherical, W.H.S.	Conical, single colour.	..	Port hand buoys are nearly always chequered or striped.
Top mark .	Staff and cage.	Diamond.	Triangle.	Staff and ball.		Starboard hand buoys are single colour distinctive from port hand buoys.
Numbers from sea.	Odd.	..	..	Even.		Top marks are single colour, generally black.
Scotland, Ireland, and Mersey.						
Shape and colour.	Can, B.	As above.		Conical, R.	..	The Mersey buoys are marked with the initial letter of their channel, and numbered consecutively from seaward.
Top mark .	Staff and cage.			Staff and ball.		
Netherlands.						
Shape and colour.	Can, B.	Sph., B. or R. or B.R.H.S.	Spherical.	Conical, R.	..	* Top marks are only put on in special cases, and are the same colour as the buoys or beacons.
Top mark .	Truncated cone.*	Diamond.	Cone.	Ball.*		Distinguishing buoys, *i.e.* lying outside, marking approaches to channels, have no special colour.
Numbers .	From seaward.	..	..	From seaward.	...	Wreck Lights—R. over W. on safe side. R. on side of Wreck.
Belgium.						
Shape and colour.	Buoyage is same as Netherlands system.					

				France.		
Colour . .	B.	W.B.H.S.	W.R.H.S.	R.	. .	For tide signals see Pilot for West Coast of France, Spain, and Portugal.
Top mark . .	Cylinder.	2 cones, points together.	2 cones, bases together.	Cone.		
Numbers . .	Odd.	*Isolated Danger*, B. and R.H.S. *Top mark*, globe.		Even.		
				Spain.		
Colour . .	B.	W.B.H.S.	W.R.H.S.	R.	. .	The seaward entrance of a channel open at both ends is the more westerly.
Top mark . .	Cylinder	Ball, B.	½ globe, R., curve up.	Cone.		Dangers advanced from coast to be left on land side are indicated by the starboard hand marks.
Numbers . .	Odd.	*Isolated Danger*, B. R.H.S. *Top mark*, globe and ½ globe.		Even.		Names of dangers are painted in white on buoys marking them.
Light buoys .	Light, R.			Light, G.		Light and sound buoys: top marks, starboard hand, small cylindrical basket, port hand, nil.
				British India.		
Colour . .	B.	. .	. .	R.	. .	Port hand buoys are black or parti-coloured.
Top mark . .	Staff and cylinder.	Globe.	½ globe, curve up.	Staff and cone.		The buoyage system is practically the same as in the United Kingdom.
				China.		
Colour . .	B.	*Isolated Danger, sea side.*	*Mid-Channel Marks.*	R.	. .	Buoys R. and B.V.S. mark ends of spits and outer and inner extremities of reefs with a channel on each side.
Obstruction .	B.W. cheq.	B.R. cheq.	R.B.H.S.	R.W. cheq.		
				Canada and U.S.A.		
Shape and colour.	Can, B.	*Isolated Dangers.*	*Mid-Channel Marks.*	Conical, R.	. .	Turning points indicated by perches, cages, and balls on a buoy.
Numbers . .	Odd.	B.R.H.S.	W.B.V.S.	Even.		If only one channel, *can* port hand, *conical* or *nun* starboard hand; or *principal* channels nun buoys, *secondary* can buoys, *minor* spar buoys.

Denmark.

	Port Hand.		*Starboard Hand.*		*Remarks.*
Entering Main channels.	Can, W. 1, 2, or 3 *down*-turned brooms on W. staff.	*Middle Grounds and Isolated Dangers.* Conical, R.W.S. Ball and staff, R.W.S.	Conical, R. 1, 2, or 3 *up*-turned brooms on R. staff.	*v.* Baltic Pilot, Pt. I., for cable beacons, storm and ice signals.	*Entering* is from the North Sea to Baltic and Danish ports in Skagerrack, Kattegatt, Sound, and Great and Little Belts. Limfiord, Smarlands, Farvandel, and fairway south of Fyen are regarded as fiords closed at Logstör, Masnedo, and Svendborg-Marstal.
Small channels.	Perch, W. 1 or 2 straw wisps.	Perch, R.W.S. Broom over straw wisp.	Perch, R. 1 or 2 brooms.		*Mid-fairway guides* to a channel from seaward are same as middle ground marks. *Winter buoyage:* large buoys are replaced by smaller, and light and sound buoys by spar or nun.

Germany (and River Ems).

		Middle Grounds	*Mid-Channel.*			
Entering . .	Conical (or beacon), B.	Buoy (or beacon), B.R.S. surmounted by a Cross.	Spherical, B.R.S.	Spar (or beacon), R.	*v.* Baltic Pilot, Pt. I., for depth of water signals and storm signals.	*Beacons* are:—*d'Alben* or groups of piles, *Perches* or single stakes with brooms, *Pricken* or small trees.
Numbered or lettered.	From seaward.		. .	From seaward.		*Entering* a channel open at both ends is the entrance in western semicircle.
		Isolated Danger Small. Buoy (or beacon), B. W.S.	Top mark, a drum.			*Sea entrances* not marked by light-ships or beacons have beacon buoys moored in sight of the nearest channel buoy.
Seaward shoal Letter and top mark.	*On N. side.* N. $\triangle$ $\triangle$	*On E. side.* O. $\triangle$ $\triangle$	*On S. side.* S. $\triangledown$ $\triangledown$	*On W. side.* W. $\triangledown$ $\triangle$		*Buoys and beacons* marking seaward shoals are W. with name of shoal in B., and letters as opposite in B. surmounted by two triangles as opposite. Wreck light buoys show G.Occ. or G.Fl.

Norway.

		Isolated Danger.	*Mid-Channel.*			
Fixed marks	Poles, pillar, or land marks. Arm thus: Γ	Pole, pillar, or land mark. Arms thus: T	Pole, B. W.H.S. Cross piece.	Poles, pillars, or land marks. Arm thus: ⅂	*v.* Norway Pilot, Pt. I., for storm signals.	*Buoys* are R., and some have top marks of colour and description as opposite. *Wrecks* marked with poles, G. Shoals with more than 16 ft. generally unmarked. Beacons exposed to heavy seas have no arms. Top marks on buoys are removed in autumn and channel shown by colour of poles only. Inner fairways frozen in winter have floating marks removed for the season.
Floating marks	Shoals, S. or W. of mark.	Pole, B. Broom up-turned or cone.	Pole, W. Broom down-turned or cone.	Shoals N. or E. of mark.		

Sweden.

	Channels running N. and S.		*Channels running E. and W.*			
	On W. side. Buoy or beacon, B. Cone thus: Δ	*On E. side.* Buoy or beacon, R. Broom over ∇	*On S. side.* Buoy or beacon, B. Cone thus: Δ	*On N. side.* Buoy or beacon, R. Broom over ∇	*v.* Norway Pilot, Pt. I., and Baltic Pilot, Pt. I.	*Isolated Dangers.*—Beacon shaped as a cross, R. and B., with 2 cones, points together, upper R., lower B. Light-vessels carry no anchor light, and by day carry skeleton balls corresponding to the number of lights shown. These are struck if the light-vessel is driven from its station. Light-vessels are painted R.
Seaward shoals	*On N. side.*	*On E. side.*	*On S. side.*	*On W. side.*		
Colour . .	Spar buoy, B.	B. with W. band	R.	R.		
Top mark . .	. .	. .	Brooms turned up.	Brooms turned down.		

Russia.

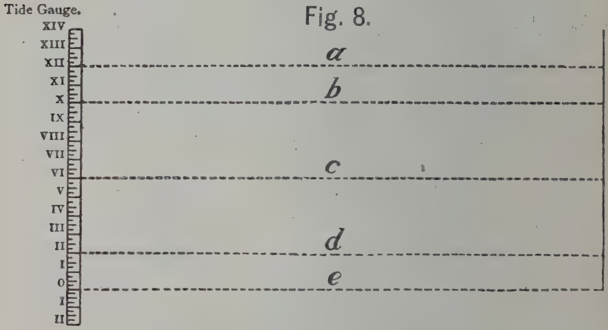
		Isolated Danger.				
	Buoys, B.	Spar, R.W. with Cross beam, R.		Buoys, W.	*v.* Baltic Pilot, Pt. II., for depth of water and storm signals.	*Isolated Dangers.*—Within Skerries, ball B. under cross beam. *Certain buoys* to distinguish from others have balls under brooms painted on N. side, B.; on E. side, W. over R.; on S. side, R.; on W. side, B. over W. *Other buoys than spar buoys* are always surmounted by a staff with the top marks and colouring of the spar buoys opposite. These buoys are painted similarly to the staff attached to each.
Shoals . .	*On N. side.*	*On E. side.*	*On S. side.*	*On W. side.*		
Colour . .	Spar, W.	Spar, W. over R.	Spar, R.	Spar, B. over W.		
Top mark .	$\overline{M}$ Broom, B.	$\underline{W}$ $\overline{M}$ 2 brooms, R.	$\underline{W}$ Broom, R.	$\overline{M}$ $\underline{W}$ 2 brooms, B.		

N.B.—These symbols indicate brooms up or down. *Up* thus, $\underline{W}$; or *Down* thus. $\overline{M}$.

Diagram to explain the terms Rise and Range of Tide.

The following diagram is intended to explain the terms Spring rise, Neap rise, and Neap range as made use of on the Admiralty charts and in the Sailing Directions published by the Admiralty.

Fig. 8.



a = Mean level of high water ordinary Springs.
b = ,, ,, ,, Neaps.
c = Half tide or mean level of the sea both at Springs and Neaps.
d = Mean level of low water ordinary Neaps.
e = ,, ,, , Springs.

Example.

	ft.
Spring rise (or mean Spring range)	$= e$ to $a = 12$
Neap rise	$= e$ to $b = 10$
Neap range	$= d$ to $b = 8$

Spring tide is taken to be the coincidence of the principal tide waves due to the sun and to the moon. This coincidence at any given place rarely occurs on the day of full or new moon, but from one to three days afterwards; and, in places where the inequalities in the tides are not great, it causes the highest tides of the lunation.

There are, however, places where the differences in water level, due to the position of the moon as regards distance, or to her position in declination, may have a greater influence in causing high tides than the fact of the coincidence of the principal sun and moon waves. In such places, the highest tides may occur rather when the moon is in perigee, or in a certain declination, but these should not be spoken of as spring tides.

(4) TIDES AND THE USE OF TIDE TABLES

Definitions of Heights and Levels

Mean Sea Level (M.L.) is the average sea level between High and Low Water marks.

Tidal Datum is the zero level from which tidal rise is measured; it is the average level of the lowest low waters in each month, or very nearly so. The Tidal Datum of each standard port is specified in the Tide Tables.

Admiralty Datum is generally the same as the Tidal Datum, and is the level for the soundings and heights marked on charts.

High Water (H.W.) is the greatest height of level in any one tide.

Low Water (L.W.) is the least height of level in any one tide.

Time of H.W. is the middle time between ceasing to rise and commencing to fall.

Time of L.W. is the middle time between ceasing to fall and commencing to rise.

Stand of Tide is the duration of H.W. or L.W. without change of level.

Spring Tides are those that rise highest and fall lowest from M.L. These occur twice in a Lunar Month, two or three days after Full or New Moon, and are those caused by the combined attraction of the Sun and Moon when the Sun, Moon, and Earth are in line (see also footnote, diagram, page 74).

Neap Tides are those that rise least and fall least from M.L. These occur twice in a Lunar Month, two or three days after Quadrature, and are those caused by the excess of the Moon's attraction over that of the Sun when the Sun, Earth, and Moon form a right angle.

Ordinary Spring Tides are Spring Tides of average rise and fall.

Extraordinary Spring Tides are those of rise and fall above average. These occur when the Moon is in Perigee (or nearest the Earth), and when the Earth is in Perihelion (or nearest the Sun).

H.W.O.S. means High Water Ordinary Springs. **L.W.O.S.** means Low Water Ordinary Springs.

Note.—The terms H.W.O.S. and L.W.O.S. will not appear on new editions of charts published subsequently to June 1914, but instead—

H.W. always refers to Mean High Water of Ordinary Springs, unless otherwise stated.
L.W. „ „ „ Low „ „ „ „ „

Rise of Tide is the height any tide rises above L.W.O.S. or L.W.

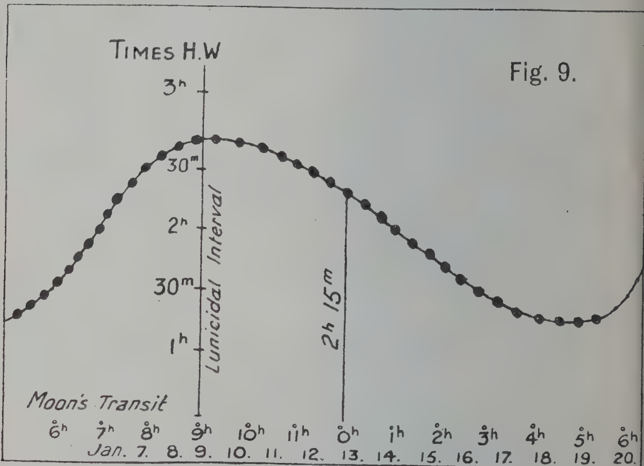
Range of Tide is the difference in height between H.W. and L.W. of any one tide.

Spring Range is the range of Spring Tides.

Neap Range is the range of Neap Tides.

Spring Rise = Spring Range, but Neap Rise does not = Neap Range (see diagram, page 74, to explain the terms "Rise and Range of Tide").

Diagram to explain the terms
L.T.I., H.W.F. & C., Mean L.T.I., Corrected Establishment, Age of Tide Semimensual Inequality, Priming and Lagging.



Vertical Parallel Lines (Ordinates) are measures of Time for Lunitidal Intervals.

Horizontal Parallel Lines (Abscissæ) are measures of Apparent Time and Date of Moon's Meridian Passage at the place.

L.T.I. on any day is the ordinate from the curve to the time of the Moon's Meridian Passage on that day.

H.W.F. & C., or Vulgar Establishment, is the ordinate at Meridian Passage of 0 hours or 12 hours.

Mean Establishment is the mean of the ordinates from the curve.

Corrected Establishment is the ordinate on the day of spring tides.

Age of the Tide is the interval from Meridian Passage at 0 hours or 12 hours to the ordinate on the day of the spring tides.

Tide is priming from 13th to 21st, *i.e.* 1st Quarter.
,, lagging ,, 7th ,, 13th, *i.e.* 4th Quarter.

Note.—Tidal Datum, Admiralty Datum, L.W.O.S. (or L.W.) are practically the same levels, and are the level to which soundings on charts are reduced. In French charts soundings are generally for Extraordinary Low Spring Tides.

Definitions of Times

Lunitidal Interval (L.T.I.) is the time between the Moon's Meridian Passage at a place and the next H.W. at that place. This interval varies every day.

Time of H.W. at Full and Change of Moon (H.W.F. & C.), or the **Vulgar Establishment** of a port, is the L.T.I. on the days of Full and New Moon. The time against a port on a chart, hours in Roman with minutes in Arabic figures, is the H.W.F. & C. at the port. H.W.F. & C. of a place is very nearly the Apparent Time at the place of H.W. at Full and New Moon, for at Full or New Moon the Moon is on the Meridian of the place at nearly midnight or noon.

Mean Establishment of a Port (Mean L.T.I.) is the mean of the L.T.I.'s in a semilunation or a fortnight.

Corrected Establishment of a Port is the L.T.I. on the actual day of Spring Tides. This occurs approximately one to three days after Full or New Moon. It is practically equal to the Mean L.T.I.

Age of the Tide is the interval between the Moon's Meridian Passage at a place at Full or New Moon and the next Spring Tide. The Age varies from one to three days, and shows the tides at the place to be caused by the Moon's attractive effect one to three days previously.

Fortnightly or Semimensual Inequality is the difference between the greatest and least L.T.I.'s in a semilunation. It is about 1½ hours.

Priming.—Tides are said to "Prime" on days that the L.T.I. is less than H.W.F. & C.

Lagging.—Tides are said to "Lag" on days that the L.T.I. is greater than H.W.F. & C.

Priming occurs in 1st and 3rd Quarters or from Springs to Neaps, and "Range of Tide" decreases.

Lagging occurs in 2nd and 4th Quarters or from Neaps to Springs, and "Range of Tide" increases.

Thus, in the 1st Quarter the Moon increases its angular distance from the Sun from 0° to 90°, and the Sun's attraction retards the tidal wave from following the Moon, the L.T.I. decreases and the Range of Tide decreases.

Again, in the 2nd Quarter the Moon increases its angular distance from the Sun from 90° to 180°, and the Sun's attraction accelerates the tidal wave to follow the Moon, the L.T.I. increases and the Range of Tide increases.

In the 3rd Quarter the action is similar to that in the 1st Quarter and that in the 4th Quarter to that in the 2nd Quarter (see diagram, page 76, explaining above definitions).

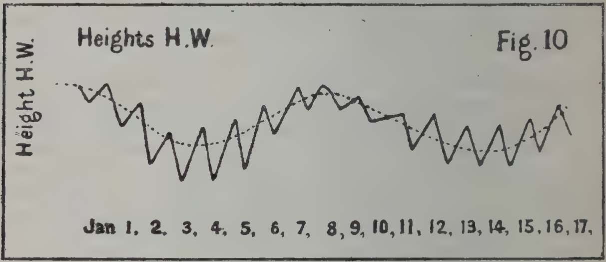
Note.—There is generally an A.M. and P.M. tide, but on one day in each semilunation there is only one tide, owing to the length of a lunar day averaging 12 hours 24 minutes.

Diurnal Inequality of Tides

From the foregoing remarks on heights and times of tides it would appear that the heights of H.W. or L.W. and the L.T.I.'s regularly decreased or increased accordingly as the tide was priming or lagging, giving a curve similar to that shown in diagram, page 76, for both, these variations being produced by the angular distance between the Sun and Moon relatively to the Earth, and recurring regularly every Semilunation.

Considerable further variations are also produced by the Sun's and Moon's Declination, but mainly by the latter.

The effect of these variations is that both the heights of H.W. or L.W. and lunitidal intervals are alternately greater or less in successive tides instead of regularly increasing or decreasing.



These variations from the curve are called the **Diurnal Inequalities** of Heights and L.T.I.'s. If the height of H.W. or L.W. or the L.T.I.'s are set off on a diagram, as fig. 10, the heights or L.T.I.'s will form a zigzag as shown, the width of the zigzag increasing from 0 to maximum and diminishing to 0 generally in the course of a fortnight, and so on perpetually.

To determine the Establishment, the zigzags of the L.T.I. must be bisected and a curve drawn through these points.

The Corrected Establishment will be the ordinate corresponding to the abscissæ of Full or New Moon 0 hrs. or 12 hrs. In using this Establishment to predict tides, it must be remembered the result will be affected by the Diurnal Inequality. Owing to Diurnal Inequality, day or night tides are often highest for months together.

The general law would appear to be—

If Latitude and Sun's Declination are both N. or both S., *i.e.* in Summer, Day Tides highest.

If Latitude and Sun's Declination are one N. and the other S., *i.e.* in Winter, Night Tides highest.

There are, however, exceptions to this.

Often the Diurnal Inequality of height of L.W. is greater than that of H.W.

Single Day Tides.—The effect of the Diurnal Inequality is sometimes so large that there is only one high tide in 24 hours. This generally happens for only a few days in each semilunation, the other days having two tides.

Double Half Tides.—In some places the tide rises or falls four times in 24 hours. These are called Double Half-day Tides.

Barometric Effects

The surface of the sea rises 20 inches for a barometric fall of 1 inch, and falls 20 inches for a rise of 1 inch.

Remarks on Tidal Streams

Time of Turn of tidal stream must not be confounded with time of H.W. Except at the head of a bay or creek, time of H.W. generally differs from turn of tide stream.

Flood Stream often runs for some time, often hours, after H.W.
Ebb ,, ,, ,, ,, ,, ,, L.W.

Turn of Tidal Stream often differs at different distances from the shore, though time of H.W. may not necessarily differ at these points.

In the centre of all open channels, when the tide runs right through, the stream almost invariably overruns time of H.W. or L.W. by about 3 hours.

Thus stream due to flood runs 3 hrs. before to 3 hrs. after H.W.
,, ,, ebb ,, ,, ,, L.W.

Near the sides of channels of any width, whose sides are shallow, the direction of the Tidal Stream is rotatory.

On Left hand, looking in direction of flood stream, rotation is Clockwise.

On Right hand, looking in direction of flood stream, rotation is Anticlockwise.

The duration of Flood stream is generally shorter than that of Ebb stream in the upper part of estuaries or tidal waters with shallow banks. This is due to the friction of the ground. Higher up the difference becomes more marked, and when the tidal range is great the water piles up, finally rushing up in a wave which in extreme cases has a nearly vertical face and is called a "bore." In such instances the whole flood may only last 2 or 3 hours, the remainder of the 12 hours being ebb stream.

Tides up deep bays and rivers are later than those at the entrance, but are not more irregular, and are often remarkably regular.

Tide in its progress up inlets and rivers is often much magnified or modified by local circumstances; for example:—

In a gulf or estuary funnel-shaped, and in the same direction as the course of the tidal wave, height is magnified as the body of the water is contracted; maximum rise is at some point short of the end of the funnel in most cases. Sometimes such a tide is divided into two half-day tides, as in the Forth.

In all cases, after a certain point, the tide dies away in ascending a river.

The wind often produces a marked effect on the tides, especially on the height.

Admiralty Tide Tables

Part I. contains Tide Tables for Standard and Secondary Ports. These are given in order round the coasts, and indexed alphabetically at the end of Part I. The following data are given:—

Standard Ports (about 54).

(*a*) Time of H.W. (also L.W. for certain of these ports) for Standard Time of place.
(*b*) Height of H.W. (also L.W. for certain of these ports).
(*c*) Tidal Constants for Secondary Ports based on the Standard Ports above.

Tidal Constants are the heights and times to be added to or subtracted from the heights and times of H.W. or L.W. (as indicated by the signs + or −) at the Standard Port to give the height and time of H.W. or L.W. at the Secondary Port.

Standard Time is the mean time kept in the country the port is situated in.

In England, Scotland, and Wales this is Greenwich Mean Time; in Ireland, Dublin M.T.

In Part I. the following information is also given:—

(*a*) Data from the Ephemeris for every day in the year in the beginning, viz. Moon's Age, Declination, Horizontal Parallax, Phases, Upper Meridian Passage; Sun's Declination, Equation of Time.
(*b*) For Standard Ports: H.W.F. & C. for Local Mean Time and Standard Time, Tidal Datum, Tidal Range, Tidal Streams.
(*c*) For Standard and Secondary Ports: Latitude and Longitude.
(*d*) For Standard Ports where only H.W. is given: Half Spring Range and approximate hours rising and falling.

Part II. contains Tide Tables for other places.

Local Mean Time and Greenwich Mean Time of High Water on Full and Change days, with the Rise of Tide at Springs and Neaps for the Principal Ports, etc., of the world arranged geographically. These places are indexed alphabetically at the end of Part II.

The Latitude and Longitude and the Longitude in time of each place are given.

The Rise of the Tide at Springs and Neaps is above the datum of the chart, unless otherwise stated.

Note.—Places of which the names are printed in small capitals are predicted.

Tidal Times and Heights

Before entering or leaving a port, it is generally necessary to ascertain—

(*a*) The Time of High Water or Low Water.
(*b*) The Height of High Water or Low Water above Admiralty Datum.
(*c*) The Rise at any time above Admiralty Datum.

For Standard and Secondary Ports the information (*a*) and (*b*) is readily obtained from the Admiralty Tide Tables.

For other places, information (*a*) and (*b*) may be deduced from H.W.F. & C.

To find (*c*), the Rise at any time above Admiralty Datum

General case, using the Traverse Table, and as example:—

Find Height of Tide above datum $3\frac{1}{2}$ hours before and $3\frac{1}{2}$ hours after H.W. at London Bridge, on a day when tide rises 18 feet 4 inches. Springs rise 20 feet 8 inches. Tide rises $5\frac{1}{2}$ hours and falls 7 hours.

Distance in Traverse Table is $\frac{1}{2}$ Tidal Range, *i.e.* (Rise of Tide $-\frac{1}{2}$ Spring Rise).

Rise of Tide (Part I. Tide Tables) = 18 feet 4 inches
$\frac{1}{2}$ Spring Rise (,, II. ,,) = 10 feet 4 inches

$\frac{1}{2}$ Tidal Range = 8 feet 0 inches
="Distance."

Angle in Traverse Table for *Course* is given thus:—

Rising tide =($180^\circ \times$ hours before H.W. $\div$ hours rising) $= 180^\circ \times 3\frac{1}{2} \div 5\frac{1}{2} = 114\frac{6}{11}^\circ$.
Falling tide =($180^\circ \times$ hours after H.W. $\div$ hours falling) $= 180^\circ \times 3\frac{1}{2} \div 7 = 90^\circ$.

Note.—If the angle is over 90°, use the supplement, *i.e.* (180° − angle found above).

Diff. Lat. in Traverse Table is the correction to add to, or subtract from, ½ Spring Rise.

Correction is + if angle is under 90°. Correction is − if angle is over 90°.

Hence 3½ hrs. before H.W. Rise = 10 ft. 4 ins. − 3 ft. 3½ in. or 7 ft. 0½ in. above L.W.
and 3½ „ after „ „ = 10 ft. 4 ins. + 0 ft., or 10 ft. 4 ins. above L.W.

Tides Rising and Falling in Equal Times

If the tide rises or falls in 6¼ hours, it is sufficiently accurate to take the time as 6 hours rising or falling.

In this case the angle for the *Course* above can be taken as 30° per hour.

Then at 3 hours before or after H.W. or L.W. the rise above Admiralty Datum on any day = ½ Spring Rise.

At 2 hours before or after H.W. or L.W. the correction to apply to ½ Spring Rise is ¼th of the Tidal Range or ½ (Rise of Tide − ½ Spring Rise).

This correction is + ½ Spring Rise 2 hours before and 2 hours after H.W., and is − ½ Spring Rise 2 hours before and 2 hours after L.W.

The approximate heights every two hours can thus be determined mentally.

To find (a)

Time of H.W. from the Establishment

The Time of H.W. or L.W. for other places than Standard and Secondary Ports is ascertained from the Vulgar Establishment, *i.e.* H.W.F. & C. or the Lunitidal interval on the days of Full and Change of the Moon.

H.W.F. & C. with Spring Rise and Neap Rise is given in—

(*a*) Part II. of the Admiralty Tide Tables.
(*b*) On charts, the hours being marked in Roman figures against most ports.
(*c*) Sailing Directions.
(*d*) Nautical Almanac for certain European ports.

Approximate computation.

(1) Ascertain time of Moon's Meridian Passage on the day. (Pages 2 to 5, Admiralty Tide Tables, or page II of month in the Nautical Almanac.)
(2) Correct Moon's Meridian Passage for Longitude. (Add 2 minutes per 15° of W. Longitude. Subtract 2 minutes per 15° of E. Longitude.)
(3) Add H.W.F. & C. to the Corrected Moon's Meridian Passage: the sum if—

Under 12 hours is S.M.T. of H.W. of P.M. tide on the day.
Over 12 hours is S.M.T. „ „ A.M. „ „ next day.
Over 24 hours is S.M.T. „ „ P.M. „ „ „ „

To find H.W. one Tide earlier, subtract 12 hours 24 minutes from the sum.

To find H.W. two Tides earlier, subtract 24 hours 48 minutes from the sum.

A more accurate method.—To more accurately determine the time of H.W., it is necessary to correct the H.W.F. & C. used in paragraph 3—the Lunitidal interval on days of Full and Change of the Moon—for the number of transits after Full or Change of Moon. H.W.F. & C. is approximately correct when the Hour of Moon's Transit after the Sun is 0 hours or 12 hours; for other times a correction is necessary. This correction also depends on the Age of the Tide.

The tables below give the correction for Age of $1\frac{1}{4}$ days and $2\frac{1}{2}$ days. In general, tides will be between these limits.

Should the Mean Establishment be known, the correction on line 3 can be used; but in taking this correction the *hour of Moon's transit on the day causing the Birth of the Tide* 1, 2, or 3 days previously must be taken.

S.M.T. of Moon's Transit: hours=	0	1	2	3	4	5	6	7	8	9	10	11
					Correction in minutes.							
Table I.—Corr. for H.W.F. & C. Age $1\frac{1}{4}$ days	0	−16	−32	−47	−57	−60	−47	−16	+15	+28	+25	+15
Table II.—Corr. for H.W.F. & C. Age $2\frac{1}{2}$ days	0	−15	−31	−47	−62	−72	−75	−62	−31	0	+13	+10
Table III.—Corr. for Mean L.T.I., *Birth Transit*	0	−16	−31	−41	−44	−31	0	+31	+44	+41	+31	+16

To find (b)

Height of Tide on any Day above L.W.O.S.

(1) For Standard Ports, Height of Tide at H.W. above L.W.O.S. is given for each day in the Tide Tables.

(2) For Secondary Ports, Height of Tide at H.W. above L.W.O.S. at Spring and Neap Tides is given by applying the Tidal Constant to the Spring and Neap Height of H.W. of the Standard Port of reference; but these constants give the height at any other day sufficiently accurately for all practical purposes, as the constant changes little between Springs and Neaps.

(3) For all other ports Spring and Neap Rise only is given.

To ascertain in case (3) the height of H.W. above L.W.O.S. on intermediate days between Spring and Neap Tides, a rough approximation may be ascertained by use of the

following table. This table must not, however, be implicitly relied on.

Tides after Spring	1	2	3	4	5	6	7	8	9	10	11	12	13
Inches reduction per ft. of difference between Spring and Neap Rise.	·2	·8	1·4	2·1	3·0	4·0	5·2	6·8	8·0	9·7	11·0	11·6	12·0

Example.—Spring Rise 14 feet 4 inches, Neap Rise 8 feet 0 inches. Find Height of H.W. above L.W.O.S. eleven tides after Spring Tide.

Spring Rise—Neap Rise = 6 feet 4 inches.

Reduction per table 11 × 6·4 inches = 704 ÷ 12 = 5 feet 10 inches.

Spring Rise 14 feet 4 inches less 5 feet 10 inches gives height above L.W.S. as 8 feet 6 inches.

SECTION (b)

Coastal Navigation

Coastal Navigation comprises navigation round coasts, from headland to headland, and generally in sight of, or sufficiently often in sight of, land to make observations of heavenly bodies unnecessary.

The duties of the navigator are—

(*a*) To determine the correct Compass Courses to steer, allowing for Current Set and Drift.
(*b*) To determine the Run or Time on each course.
(*c*) To keep clear of shoals or other dangers.
(*d*) To " Fix " frequently the position of the ship.

Before leaving one port for another on a coastal passage, it is desirable to determine beforehand, for the speed at which the ship will proceed—

(1) The various Compass Courses to steer ;
(2) The Run or Time on each course ;

due allowance for Set and Drift of Tidal Streams or Currents being made.

Previously prepared data such as are indicated further on should be invaluable when making the same passage in foggy or misty weather, for the navigator is thereby enabled to direct his whole attention to conning the ship, fixing, noting the soundings, and generally keeping a good look-out ; and his attention is not diverted by referring to charts, laying off courses, etc.

While on passage the Courses and Runs computed should be checked by those actually steered, and any errors in the former corrected. Or a comparison of the computed Course and Run with the actual Course and Run made good, will enable a correct estimation of the Set and Drift of the Tidal Stream or Current to be determined, as explained on pages 92 and 94. In this manner useful records are obtained, for future reference, that should be of great value and give confidence when making the same passage in thick or foggy weather, and save the labour of working out Courses and Runs on the next occasion.

In war-time such records might be especially valuable, when it is probably necessary to make passages under any conditions of fog and at speeds greater than are permissible in peace.

On making the Allowances for Tidal Set and Drift.

When making a coastal passage it is frequently desirable to arrive at a certain place by a certain time, possibly to catch a tide, for daylight, or for other reasons ; and to do this passage at a constant speed, probably the economical speed of the vessel.

The speed and time of arrival being thereby settled, the time of departure must be ascertained. This is best done by making up a record by working back from the destination and required time of arrival there, for in this manner Set and Drift of Tidal Streams can be correctly and conveniently determined and allowed for.

A suggested more convenient form than the Ship's Log Book for making these records is shown in the facsimile of the Dead Reckoning Book. The facsimile of the Dead Reckoning Book given shows a record prepared before leaving Portsmouth for the Swarte Bank, lat. 53° 15′ N., long. 2° 31′ E.

The ship was directed to proceed at 11 knots and be in above position by 8.30 A.M. May 4th.

The Tidal Sets and Drifts to allow on each course were ascertained by working backwards to Portsmouth from the rendezvous at 8.30 A.M. May 4th.

It was thus found that for the speed of 11 knots the ship should leave at 11 A.M. the previous day, May 3rd.

The speed remained constant throughout, and the following small errors in the calculated times were found on passage, viz. the ship passed Royal Sovereign Light-vessel 5 minutes late, South Goodwin 2 minutes late, arriving Swarte Bank 2 minutes late.

Making and Checking a Record for Coastal Navigation in the Dead Reckoning Book

On the Left-hand page fill in as follows :—

Column.

1 and 2. Names in consecutive order of Points, Headlands, Lights, etc., at which course is altered, or the names of conspicuous objects passed.

3. Distance in nautical miles between the objects in Columns 1 and 2.

6. Magnetic Course from object in Column 1 to that in Column 2.

Note.—Correct the Magnetic Course from the chart for annual change of Variation.

7. The Speed or Speeds at which the ship will proceed.

8 and 9. Current or Tidal Set and Drift when making each run.

Note.—Tidal Set and Drift can be taken from Charts, Sailing Directions, "Tidal Streams for British Isles," or at light-vessels from Admiralty Light List.

Note.—To accurately and conveniently allow for the Set and Drift, work back from the destination as explained. Thus :—It is required to arrive at Swarte Bank at 8.30 A.M.; hence ship must pass Smith's Knoll light-vessel at about 7 A.M. Between 7 A.M. and 8.30 A.M. the Set in that vicinity is 212°. and the Drift 0·48 knots.

Column.

4 and 5. Should be filled in while on passage with the Patent Log distance and the number of revolutions when passing from object in Column 1 to that in Column 2.

On the Right-hand page fill in as follows :—

Column.

1. Compass Course to steer, *i.e.* Mag. Course corrected for Deviation, and Set and Drift of Current allowed.
2. The Speed (Column 7, left-hand page) corrected for Set and Drift.
3. The Time on each Course. Divide the Distance (Column 3, left-hand page) by the Speed (Column 2, right-hand page).
4. This should be filled in while on passage with the exact times at which the objects in Column 2 are passed, and afterwards compared with the computed time-intervals.

The Remarks Column should contain particulars and times of Fixes, Bearings, Transits, Soundings, Alterations of Clock, and Changes in the Temperature of the Sea-water, Force and Direction of Wind.

From Portsmouth to Swarte Bank. Date 23rd May 1911. Time of H.W. at Dover, A.M. 6 *hrs.* 15 *mins.;* P.M. 6 *hrs.* 46 *mins. Draught Forward,* 15 *ft.* 3 *ins.; Aft,* 20 *ft.* 4 *ins.*

From	To	Distance.	Patent Log.	Total Revs.	Course Magnetic.	Speed.	Current. Set.	Current. Drift.	Course steered.	Speed made good.	Time. Intervals.	Time. Clock.	Remarks and Fixes.
		Naut. miles.		Mean of two propellers.							h. m. s.	h. m. s.	
Nomans' Fort	Nab Buoy .	4·2	4·25	1,702	145·5		Nil.	Nil.	144	11·0	0 23 0	11 2 0	10.27 slipped and proceeded 10.38; 74 revs.
Nab Buoy .	Owers Lt. Vessel	12·8	13·85	5,555	129		308°	·88	128	10·24	1 15 0	11 25 0	..
Owers Lt. Vessel	Royal Sovereign	42·2	41·5	16,650	99	11·08 or 74 revs. per min.	97°	·13	100	11·25	3 45 0	12 40 0	1.5 Beachy Hd. 323½°, East Pier 353½°, Royal Sov. 81°.
Royal Sovereign	Dungeness .	24·0	22·75	9,102	74		74°	·58	74	11·66	2 3 30	4 25 0	6.18 Dungeness 31·5°, Water Tower 11°.
Dungeness .	South Goodwin	23·0	21·40	8,547	62·5		83·5°	·9	61	11·94	1 55 30	6 28 30	7.53 Folkestone 290·5°, Dover Lt. 28°, N. Foreland 43°.
South Goodwin	Gull Lt. Vessel	7·2	6·5	2,590	18		34°	1·3	15 (16° mag.)	12·34	0 35 0	8 24 0	11.30 Kentish Knock 216°, Longsand 340°.

Gull Lt. Vessel	Gull Elbow Buoy	4·0	5·3	2,220	42	11·08 or 74 revs. per min.	226°	3·1	43	8·0	0 30 0	8 59 0	11.43 Longsand abeam.
Gull Elbow Lt. Buoy	Kentish Knock L.V.	17·8	17·25	6,882	30·5		67°	·5	28 (29° mag.)	11·5	1 33 0	9 29 0	12.19 Sunk 266·5°, Longsand 225°.
Kentish Knock L.V.	Longsand L.V.	8·5	7·6	3,034	28		65°	1·6	22 (23° mag.)	12·4	0 41 0	11 2 0	12.56 Shipwash 289°, Orfordness 309°, Outer Gabd., 66°.
Longsand L.V.	Shipwash	14·0	12·95	5,180	28		74°	1·3	22 (23° mag.)	12·0	1 10 0	11 43 0	1.24 Shipwash 256·5°, Orfordness 277·5°, Southwold 348°.
Shipwash	Smith's Knoll L.V.	53·5	58·85	23,588	32		212°	·98	32	10·1	5 18 0	12 53 0	2.51 Orfordness 278°, Lowestoft 326°.
Smith's Knoll L.V.	Swarte Bank	25·0	26·1	10,434	32		212°	·48	32	10·6	2 21 0	6 11 0	6.3 Smith's Knoll 324°. 3 miles.
	Totals	..	238·3	95,434							21 30 0	8 32 0	Lat. 53° 15′ N., long. 2° 31′ E.
	Revs. per 1 mile 400·5												(1) Keep one sounding machine going. (2) Note force and direction of wind. (3) Note changes of sea-water temperature. Wind light, N.W.

Tidal Streams and Currents

Tidal Streams are streams caused by the Tidal Wave being restricted in its motion by land.

A Flood Tidal Stream is the stream caused by a rising tide.

An Ebb ,, ,, ,, ,, falling tide.

Currents are streams in the oceans and seas otherwise caused than by the Tidal Wave; for example, the ocean currents caused by constant winds such as the Trade Winds, the current in the Dardanelles caused by the rivers flowing into the Black Sea, and the currents in the Straits of Gibraltar caused by the temperature and salinity of the Mediterranean Sea being greater than those of the Atlantic Ocean outside the Straits.

A Drift Current is the effect of wind on the surface of the ocean, and is always slow, shallow, and to leeward.

A Stream Current is generally the resultant of a Drift Current restricted in its movement by land—for example, the Gulf Stream. Stream Currents may be rapid, vary in rate, extend deep, and may flow to windward.

The Set of a Current or Tidal Stream is the direction towards which it flows.

The Drift of a Current or Tidal Stream is its rate in knots—a knot being the speed of one nautical mile per hour.

Information on Tidal Streams and Currents is given in—

(*a*) Charts.
(*b*) Sailing Directions.

On Tidal Streams, when in the vicinity of the British Isles, the "Pocket Atlas (Tidal Streams) British Isles" will be found invaluable, or "Tides and Tidal Streams British Isles, the North Sea, and North Coast of France."

Tidal Streams at light-ships are given in the Admiralty Light Lists.

On Ocean Currents, the "Wind and Current Charts" and various publications of the U.S. Bureau of Navigation should be consulted.

(*a*) **Charts.**—Tidal Streams and Currents are shown by arrows. The arrows show the Mean Direction and Speed; both Set and Drift may vary. The indications of the arrows are :—

Feathered on one side thus, ⟶ indicates a Flood Tidal Stream.
Not feathered ,, ⟶ ,, an Ebb ,, ,,
Feathered on both sides, thus ⟶ indicates a Current.

Other information as to abbreviations is given in Chart Abbreviations, page 46.

Note (1).—Roman figures and dots refer to the hour of Flood or Ebb *by the shore* unless otherwise stated.

Note (2).—Information on charts should be taken in preference to that in Sailing Directions, if the two differ, especially when the chart is of later date.

(*b*) **Sailing Directions** give much valuable information on Tidal Streams and Currents and the effect of gales thereon.

Sailing Directions should always be studied before sailing, and especially before anchoring in exposed or open roadsteads, as exemplified in the loss of H.M.S. *Assistance* in Tangier Bay.

(*c*) **Tidal Atlases,** such as "Pocket Atlas (Tidal Streams) British Isles" and similar publications, should be closely studied when navigating round the British Isles and North Sea. The Pocket Atlas is invaluable, and gives—

(1) The direction of the Tidal Streams for every hour of the tide at Dover.
(2) The localities where the tide is rising or falling.
(3) The time of H.W. or L.W. round the coasts as compared with Dover.

In these waters the Tidal Streams are as intricate as anywhere else in the world, and, owing to the prevalence of fog and thick weather at all times, the study of the streams is most important. This was exemplified in the stranding of H.M.S. *Edinburgh* off the Isle of Wight.

(*d*) **Admiralty Light Lists** give the Tidal Streams and Currents at all light-ships, and their study is especially valuable in coastal navigation or when making a light-ship, to avcid being set too close thereto, particularly when passing ahead of a light-ship.

(*e*) **Wind and Current Charts** are valuable in ocean navigation (Section (*c*)). Whenever land is approached the navigator should guard against Stream Currents.

Sudden changes in the sea-water temperature are a sure indication of a Stream Current, and great care should be exercised. This danger was exemplified by the loss of H.M.S. *Bedford* in the Yellow Sea.

(1) Laying off the Correct Compass Course to steer

If the Set and Drift of the Tidal Stream or Current is known :—

Mark on the Chart the Ship's Position (A) and the next "Alter Course Point" (B).

If the "Alter Course Point" lies off a promontory, rock, or other danger the distance of this point B off the danger should be based on—

(1) The distance from A to B.
(2) The possible steering error.
(3) The direction and force of the wind, if setting to or from the danger.
(4) The possibility of unknown currents.
(5) The distance of visibility or clearness of the weather.

A Steering Error of 1° would cause an error of 1·8 miles in 100 miles run, and in such a case B should be at least 2 miles off the danger.

(1) Having fixed B, rule on the chart a line from A to B.

(2) From A lay off the Tidal or Current Set and Drift in 1 hour as AC.

(3) From C describe a circle, with radius the distance steamed in 1 hour. Let this circle cut AB in *b*.

Then C*b* is the True Course to steer, allowing for Tidal Stream or Current, and A*b* measures the distance made good in direction AB in 1 hour.

(4) Measure the direction C*b* with parallel rulers and the compass on the Chart.

If the True Course is measured for a Gyro Compass, this must be corrected by the Gyro Compass Tables for the Speed and the Course A*b* and not C*b*.

If the Magnetic Course is measured, the Variation of the Magnetic Compass on the Chart must be corrected for the annual change of Variation.

(5) Correct the Magnetic Course for Deviation.

This gives the Compass Course to steer, allowing for Tidal Stream or Current.

Note (1).—The Tidal Stream, Current, and Variation may vary during the run from A to B, in which case it may be necessary to ascertain the Compass Course above frequently (for example, every hour).

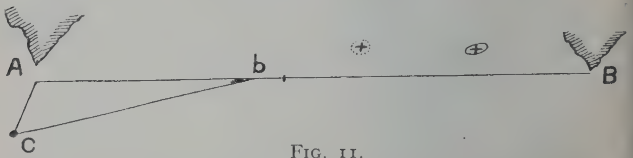


FIG. 11.

Note (2).—See also page 30, on "Laying off Courses."

(2) Measuring the Distance or Time on a Course

The Distance Made Good per hour, referring to fig. 11, is A*b*.

The Time Taken is the distance AB divided by A*b*.

The Distance Steamed through the water and measured by Patent Log or Revolutions is (Time Taken × Speed of Ship in knots) or AB ÷ A*b* × Speed in knots.

This is the distance that is actually measured by the Patent Log or by the Number of Revolutions run.

Distance by Patent Log will underlog the run if the log is temporarily foul, or by increased slip of the log at high speeds.

Distance by Revolutions will overlog if the ship's bottom is foul or if there is a head wind or sea.

Hence distance by Patent Log and distance by the Number of Revolutions are oppositely affected in regard to probable errors, and the records of each should be compared and the mean of the runs generally taken.

Distance through the water is generally very accurately measured by the number of revolutions recorded, if tables are drawn up to correct the distance for—

(*a*) Increased slip at high speeds.
(*b*) Effect of head wind.
(*c*) Effect of head sea.
(*d*) State of ship's bottom, based on the period since the ship was last docked.

Such tables are much used on Atlantic liners, which to a great extent measure their runs in this manner.

Table connecting Time and Distance at various Speeds

The " Table of Proportional Parts " at the end of the Nautical Almanac is very suitable.

To find the Distance run in a part of an hour :—Enter the table with the speed in two hours at the top, and opposite the minutes in the left-hand column read the corresponding distance run.

To find the Time in running a distance :—Enter the table with the speed in two hours at the top, and opposite the distance run in this column read the number of minutes taken in the left-hand column.

(3) Ascertaining Set and Drift of Tidal Stream or Current

In coastal navigation the following two problems frequently arise:—

(1) Finding Set and Drift from a light-vessel's distance when abeam, no Set and Drift having been allowed.

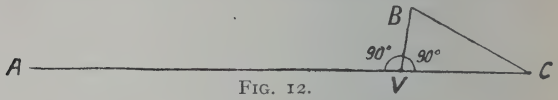


FIG. 12.

EXAMPLE.—Light-vessel bears 95°, distant 100 miles, Ship steams 95° at 17 knots. Light-vessel when abeam is 185°, distant 15 miles. Patent Log and Revolutions give a run of 136 miles.

Let A be the departure point and V the light-vessel (fig. 12).

Along AV measure 136 miles, AC.

From V lay off the position of the ship when abeam, VB=5° −15 miles.

Join CB. Then CB is the total Set and Drift, viz. 298°, miles 39.

The time taken is 136÷17, or 8 hours.

Hence the Set and Drift per hour is 298°, knots 39÷8, or 4·9.

(2) Finding the true Set and Drift from a light-vessel's distance when abeam, an erroneous Set and Drift having been allowed.

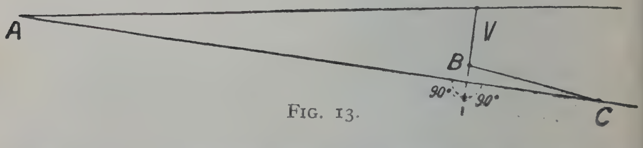


FIG. 13.

EXAMPLE.—Light-vessel bears 95°, distant 100 miles. Ship assumes Set 298° and Drift 4·9 knots, and consequently steams 101·5°, knots 17, as ascertained by method explained page 92.

Light-vessel when abeam bears 11·5°, distant 10 miles. Patent Log and Revolutions give a run of 119 miles.

Let A be the departure point and V the light-vessel (fig. 13).

From V lay off the position of the ship when abeam, VB=191·5° −10 miles.

Through A rule a perpendicular to VB, *i.e.* in the direction 101·5°, and measure in direction 101·5° from A a distance AC=119 miles.

Join CB. Then CB is the true total Set and Drift, viz. 286°, miles 19·5.

The time taken is 119÷17, or 7 hours.

Hence the Set and Drift per hour is 286°, knots 19·5÷7, or 2·8.

(4) Position Lines

A Position Line (P.L.) is a straight line in a given direction from an object whose position is known.

Note.—A P.L. lies in the plane of the Great Circle passing through the object in the given direction. As the distance of an object in "fixing" is not great, no appreciable error is introduced in representing P.L.'s as straight lines on Mercator's Charts.

The P.L. on which an observer is situated is ascertained in two ways, viz. :—

I. At any moment by ascertaining the Compass Bearing of a known fixed object.

The P.L. then of the observer at that moment is the line on a Mercator's Chart drawn through the object in the direction of the object's True Bearing. Such a P.L. is called a "Bearing."

II. By noting the moment when two fixed objects of known positions are in line with each other.

The P.L. of the observer at that moment is the line on a Mercator's Chart drawn through the positions of the two objects. Such a P.L. is called a "Transit," "Clearing Mark," or "Leading Mark."

Precautions in taking Bearings

(1) Do not touch or swing the compass.
(2) Select an object not too far off.

Note.—If the object is 10 miles distant, an error of 2° in bearing gives an error of two-thirds of a mile.

Precautions in laying off Bearings

(1) Correct the Compass Bearing,—for Deviation in a magnetic compass, or Ship's Course and Speed in a gyro compass,—before using the compass on the chart.
(2) Allow for the annual change of Variation in using the compass on the chart.
(3) Ascertain if a possible error of 1° or 2° in the bearing will put the P.L. in dangerous proximity to a shoal.

Precautions in using Transits, Clearing Marks, and Leading Marks

(1) Ascertain that the correct objects are used, *i.e.* compare the bearing of the objects when in line with their mutual bearing on the chart.
(2) Ascertain that the objects are sufficiently far apart to open directly the ship is off the P.L. As a rough guide, the distance apart of the objects should exceed $\frac{1}{5}$th to $\frac{1}{4}$th of the greatest distance at which they are used.
(3) Ascertain that the objects will open well on either side before the ship is in dangerous proximity to a shoal or other danger.

(5) Position Circles

A Position Circle (P.C.) is a circle of known radius and of known centre on the circumference of which the observer is situated.

Note.—A P.C. is a small circle whose plane is perpendicular to that radius of the earth passing through the known centre. As, however the distance of an object in "fixing" is not great, no appreciable error is introduced in representing P.C.'s as circles on Mercator's Charts.

The P.C. on which an observer is situated is ascertained in two ways, viz. :—

I. At any moment by ascertaining the angle (α) in a vertical plane subtended by the height (h) of a fixed object.

Then the P.C. of the observer at the moment is the circle of radius $=(h \times \text{cotangent } \alpha)$ whose *centre* is the base of the vertical object.

Such P.C.'s are termed "Vertical Angle P.C.'s," but as the angles measured are small they must not be relied on for great accuracy.

II. At any moment by ascertaining the angle (α) in the horizontal plane subtended by the distance (d) between two fixed objects.

Then the P.C. of the observer at the moment is the circle of radius $= (\frac{1}{2}d \text{ cosecant } \alpha)$ the *circumference* of which passes through the two fixed objects.

Such P.C.'s are termed "Horizontal Angle P.C.'s" and are highly accurate for fixing providing the angle observed is large, say over 30°.

To describe a Vertical Angle P.C. (fig. 14)

The radius ($r=h$ cotangent α) can be found by—

(1) The Table of Masthead Heights. (Inman's Tables.)

(2) r (in nautical miles) $= \dfrac{34 \times h \text{ (in feet)}}{\alpha \text{ (in seconds)}}$ gives a fairly accurate result.

(3) Lecky's Tables of Heights and Distances.

Note (1).—The radius of the P.C. on the chart must be measured on the latitude scale. The centre of the P.C. is the position of the vertical object (*v.* pages 39 and 45).

Note (2).—Heights of lighthouses and of light-vessels are given on charts and in the Admiralty Tide Tables thus :—

Lighthouses.—Height of *centre* of lantern above H.W. (Mean High Water Springs).
Light-vessels.— „ *top* „ „ Water Line.

Precautions to take in observing Vertical Angles

(1) If the angle is subtended by the height of a lighthouse or shore mark, allow for the height of tide.

(2) Small angles observe "on" and "off" the arc and take their mean. This eliminates Index Error.

[To face p. 96.

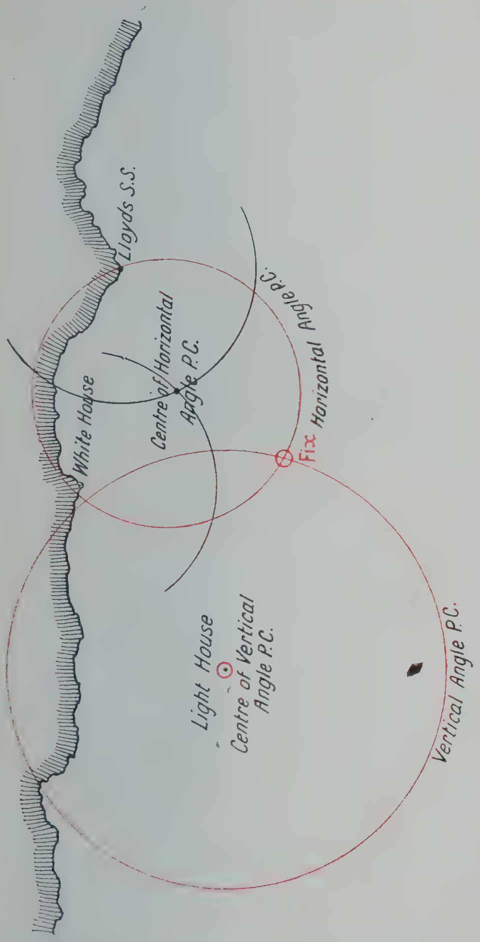


FIG. 14.

(3) Observe the angle from a position near the water line. This eliminates "Dip" (*v.* page 128) very nearly.
(4) Remember that the distance measured or the radius of the P.C. is to the spot vertically below the highest point and not to the water line.
(5) If the height (h) of a mountain inland is measured, the "Dip" of the horizon to the shore water line must be allowed for; though any error on this account is inappreciable if—

$(d-i)$ is greater than (i) or if (h) is greater than (i),

where (d) is the distance of the observer from the shore line, and (i) is the distance of the shore line from the spot vertically below the summit. (See Lecky's Distance Tables.)

To describe a Horizontal Angle P.C. (fig. 14)

The radius ($r=\frac{1}{2}d$ cosecant α) can be found by—

(1) The Traverse Table, where r = the distance, $\frac{d}{2}$ = the Departure, and α = Course.
(2) By projection on the true compass on the chart, thus:—

From radius 0° lay off the angle observed on the compass graduated from 0° to 360°.

From the centre along radius 90° lay off $\frac{d}{2}$ on the scale of the latitude.

From the point $\frac{d}{2}$ draw a normal to radius 90° meeting the angle radius laid off, at r.

Then the length from the centre to r is the radius of the observer's P.C., and is laid off on the chart thus:—

Describe two circles with centres at the objects observed, and radius as found above.

With centre where the two above circles intersect, describe a third circle of same radius.

This latter circle is the P.C. of the observer.

The first two circles intersect in two points, and the correct point of intersection to take as centre of the P.C. can be readily determined by inspection when the circles make a good cut.

Precautions to take in observing Horizontal Angles

(1) Choose objects sufficiently far apart to subtend an angle of about 30° between them.
(2) If possible, the objects should lie beyond the ends of outlying shoals and dangers.
(3) If possible, the line joining the objects should be nearly parallel to the ship's course, one object being before and the other abaft the beam.

(6) Avoiding Dangers

Dangers are avoided by keeping on, or on the safe side of, Position Lines, or outside Position Circles, providing these P.L.'s or P.C.'s clear the danger.

Such P.L.'s are called "Clearing Marks," and such P.C.'s give angles called "Danger Angles."

A Clearing Mark that depends on the True Bearing of a known object, if marked on the chart, is shown by a line from the object.

The name of the object and its True and Magnetic Bearing from seaward on this P.L. are marked against this line (*v.* "Precautions in laying off Bearings," page 95).

A Clearing Mark that depends on the Transit of two objects, if marked on the chart, is shown by a line through the two objects.

The names of the objects and their True and Magnetic Bearing from seaward when in line are marked against this line.

Note.—In both above cases the line on the chart is double or solid where safety lies, and dotted over banks, etc., to guide the eye to the objects.

A Vertical Danger Angle is the maximum angle subtended by a vertical object to keep the observer on a P.C. at a safe distance.

This V.D.A. is found by describing a circle with the position of the vertical object as centre, to include the danger. The angle subtended from this P.C. by the height of the object is then ascertained.

Thus the V.D.A. $= \text{tangent}^{-1}\dfrac{h}{r}$. This may be found as on page 96.

A Horizontal Danger Angle is the maximum angle subtended by the distance apart of two objects to keep the observer on a P.C. at a safe distance.

This H.D.A. is found by describing a circle passing through the two objects selected so as to include the danger. The angle subtended from this P.C. by the distance between the two objects is then ascertained.

Thus H.D.A. $= \text{sine}^{-1}\dfrac{d}{2r}$. This may be found as on page 96.

(7) Fixing the Position

Fixing is determining the position of the observer by the intersection of P.L.'s or P.C.'s or of P.L.'s and P.C.'s. Thus a " Fix " may be obtained by the intersection of two P.L.'s or of two P.C.'s or of a P.L. and a P.C.

If a further P.L. or P.C. is obtained in conjunction with the above, all three should cut in the same point to give a good Fix.

Precautions in Fixing

(1) Mark against each Fix on the chart the date and time of the Fix.
(2) Enter details of all Fixes (Bearings, Transits, Angles, etc.) in a note-book.
(3) P.L.'s or tangents to P.C.'s, at their point of intersection, should not, if possible, include a smaller angle than 30° to get a good Fix.
(4) Each Fix should be the centre of a small circle, which latter should include the position of the ship, allowing for all errors. This circle should be drawn, to the judgment of the observer, on the scale of the chart.

Useful Abbreviations in entering Fixes

ϕ for " in transit " or " in line with." Thus—" Church ϕ White House."

Degrees for Compass Bearing. Thus—" Church 340° " means Church bears 340°.

S. Degrees for Sextant Angle between two objects. Thus —" Church S65° Tower " means the angle between the Church and Tower from the observer is 65°, the Church being the left-hand object and the Tower the right-hand object.

Methods of Fixing

The following are some of the common methods of Fixing, but other combinations of P.L.'s and P.C.'s can be used :—

(1) Bearings of two objects, or two bearings of the same object with a Run between.
(2) Two Transits.
(3) Two Vertical Angles.
(4) Two Horizontal Angles.
(5) Bearing and Transit.
(6) Bearing and Vertical Angle.
(7) Bearing and Horizontal Angle.
(8) Transit and Vertical Angle.
(9) Transit and Horizontal Angle.
(10) Vertical Angle and Horizontal Angle.

Accurate Fixes are obtained by the pairs 2, 3, 4, 8, 9, and 10 above, as no compass bearings are used. Such fixes should be used when adjusting compasses, range-finders, and gun-sights.

Laying off Fixes on the Chart

(*a*) **Bearings of two objects** (1)—**Two Transits** (2)—**Bearing and Transit** (5).

Lay off the P.L.'s (*v.* page 95). Then the point of intersection F is the " Fix."

(*b*) **Two Bearings of one object**—with a Run between the observations.

(1) Lay off both P.L.'s from the object (*v.* page 95).
(2) From a point (*a*) on the first P.L. lay off (*ab*) the Run between the observations.
(3) From the point (*b*) lay off the Set and Drift (*bc*) between the observations.
(4) Through (*c*) rule a line parallel to the 1st P.C., cutting the 2nd P.C. at F.

Then F is the " Fix " at the instant of taking the 2nd observation.

Note.—If three bearings are taken, with a run after each observation, move the 1st and 2nd P.L.'s each its respective " Run " and Set and Drift to the 3rd observation. These three lines, to obtain a good Fix, should intersect at the same point.

(*c*) **Bearing and Vertical Angle** (6) or **Transit and Vertical Angle** (8).

(1) Lay off the Bearing or Transit (*v.* page 95) and obtain a P.L.
(2) Find the radius of the P.C. (*v.* pages 96 and 97) and describe the P.C.

Then the point F where the P.L. and P.C. intersect is the " Fix."

(*d*) **Bearing and Horizontal Angle** (7) or **Transit and Horizontal Angle** (9).

First. When the Bearing or Transit object forms with another object the Horizontal Angle:

(1) Lay off the Bearing or Transit (*v.* page 95) and obtain a P.L.
(2) Lay off the Horizontal Angle towards the 2nd object from this P.L.
(3) Through the 2nd object draw a parallel to the line forming with the P.L. the Horizontal Angle, and let this parallel cut the P.L. in F. Then F is the " Fix."

Second. When the Bearing or Transit objects do not form the Horizontal Angle:

(1) Lay off the Bearing or Transit (*v.* page 95) and obtain a P.L.
(2) Find the radius of the P.C. (*v.* pages 96 and 97) and describe a P.C.

The P.L. and P.C. intersect in two points; inspection or another Bearing will determine the "Fix."

(*e*) **Two Vertical Angles—Vertical and Horizontal Angle—Two Horizontal Angles.**

Find the radii of the P.C.'s (*v.* pages 96 and 97) and describe the P.C.'s.

The P.C.'s intersect in two points; inspection or a Bearing will determine the "Fix."

Care should be taken that the tangents to the P.C.'s at their intersection make a good cut of about 30°. This can be judged by eye.

(*f*) **Two Angles** with a Run between the observations.

Move the centre of the 1st P.C. like a P.L.—the "Run" and "Set and Drift" between observations.

Then with this new centre redescribe the 1st P.C. The intersection as before is the "Fix."

In this manner continual Fixing *using a sextant only* can be carried out during a coastal passage.

Two Horizontal Angles—Using the Station Pointer.

The Station Pointer is an instrument for "Fixing" in the special case where *two* Horizontal Angles are measured between *three* different objects.

The three legs of this instrument are set to form the angles observed, and the instrument laid on the chart with the bevel edge of each leg lying exactly on its appropriate object. When the legs are thus fitted in to the objects on the chart the centre of the instrument gives the "Fix."

Great care must be taken that the edges of the Station Pointer legs lie exactly on the objects observed. In some cases a very small error in the "Fit" may cause a very large error in the "Fix."

The disadvantage of the Station Pointer lies in the fact that the P.C.'s of the measured angles might coincide and thereby render the observations useless through the objects and observer lying on the circumference of a circle that passes through all.

To avoid this danger the following precautions should be taken:—

(1) Select the three objects in the same straight line; or
(2) Select the centre object to lie on the same side of the line joining the other two objects as the observer.

For accurate Fixing, or if any doubt exists as to whether the P.C.'s coincide or not, always describe the P.C.'s with divider compasses as in previous paragraph (*e*). A good or bad cut of the P.C. is then readily detected.

Fixing by Divider Compasses as in paragraph (*e*) has the following advantages over the use of the Station Pointer :—

(1) It can be ascertained at a glance if the P.C.'s make a good cut.

(2) The P.C.'s cannot coincide without its being instantly detected.

(3) The Fix is more accurate, as there is not the possible error of the Station Pointer fit.

(4) It is not important to confine the angles to three objects, as four may be used if a suitable three are not available. Thus two objects on one side and two on the other side of an estuary may be used.

(8) Sounding without Tubes

TABLE for ascertaining the depth of water at different speeds from amount of wire out, as given by dial of Thomson's Machine, using Wire 7 stranded circumference 0·19 inch, Lead 24 lbs., or Wire 7 stranded circumference 0·27 inch, Lead 37 lbs. Rate of descent $2\frac{1}{2}$ fathoms per second.

Thomson's Dial Reading.	Speed in Knots.													
	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	Depths.													
fms.	fms.	fms.	fms	fms.	fms.	fms.	fms.	fms.	fms.	fms.	fms.	fms.	fms.	fms.
10	9	8	8	7	6	6	6	6	6	5	5	5	4	4
15	13	12	11	11	10	10	9	9	8	8	7	7	6	6
20	17	16	15	14	13	13	12	12	11	10	10	9	8	8
25	21	20	19	18	16	16	15	15	14	13	12	11		
30	25	23	22	21	19	19	18	17	16	15				
35	29	27	26	25	22	22	21	20						
40	32	31	29	28	25	25								
45	36	34	33	31										
50	39	37												

Note.—This table must be used with the greatest caution, and only taken as giving an approximation to the depth, because it has been found on further experience that the proportion of depth to the amount of wire out for a given depth and speed varies with each sounding machine, and even with the same machine as the parts wear.

SECTION (c)

Ocean Navigation

Ocean Navigation comprises navigation out of sight of land from point to point on Rhumb Line or Great Circle Tracks.

The Rhumb Line Track, or the course a ship steers by compass, cuts all meridians at the same angle, and is therefore correctly represented by a straight line on a Mercator's Chart.

The Great Circle Track between two places is the True Bearing of the one from the other, and is the minimum distance between the two. The Great Circle Track is correctly represented as a straight line on Great Circle Charts, but a ship cannot steer along such a track without continually altering course.

Ocean Navigation consists, therefore, in steering on Rhumb Line Tracks from point to point, the points being taken on the Rhumb Line Track or Great Circle Track joining the departure point with the ship's destination. The ship's position is ascertained or "Fixed" at such points (or more frequently) by observations of heavenly bodies.

Comparison between "Fixing on Terrestrial Bodies" and "Fixing on Celestial Bodies"

Fixing on terrestrial bodies consists in determining the observer's position by the intersection of vertical planes passing through the observer and the terrestrial body, the position of the latter being known (*v.* Section (*b*)).

Fixing on celestial bodies consists in determining the observer's position by the intersection of Position Lines perpendicular to vertical planes passing through the observer and the celestial body, the position of the latter being calculated; the distance of the Position Lines from an assumed position of the observer is also calculated. The intersection of two such Position Lines gives the "Fix." This method of fixing is called (after the originator) Marc St Hilaire's method.

Now, at any given instant a celestial body is exactly overhead at some spot on the Earth's surface, and Marc St Hilaire's method may alternatively be said to consist in determining the observer's Azimuth and Distance from such point. The determination of this point depends on the position of the celestial body in the heavens, as viewed from the centre of the Earth, or depends on what is termed the "Apparent Place of the Heavenly Body."

A fuller description of Marc St Hilaire's method of fixing is given on page 131.

The Apparent Place of a Heavenly Body

The Apparent Place of a heavenly body is determined by its Right Ascension (*v.* page 113) and its Declination (*v.* page 117), both of which are affected by—

(*a*) Proper Motion, *i.e.* any real motion of the body itself. This is small except in the case of the Moon or Planets.

(*b*) Aberration, *i.e.* the apparent displacement of the body due to the relative velocity of the speed of light and the Earth's spinning and orbital speed.

(*c*) Precession, *i.e.* the alteration of the direction of the Earth's axis, mainly due to the Sun's attraction on the protuberant masses at the Earth's equator.

(*d*) Nutation, *i.e.* the nodding of the direction of the Earth's axis, mainly due to the Moon's attraction on the protuberant masses at the Earth's equator.

(*e*) The Earth's orbital motion round the Sun. This alters the Right Ascension and Declination of the nearer heavenly bodies, *i.e.* Sun, Moon, and Planets, but not those of the stars.

When all the above phenomena have been allowed for, the resulting Right Ascension and Declination give the Apparent Place of the heavenly body as viewed from the centre of the Earth. This Apparent Place is used in all calculations for fixing an observer's position.

Now, that point on the Earth's surface *vertically below* any given heavenly body alters continually in consequence of the Earth's revolution on its axis; consequently the Azimuth (*q.v.*, page 123) and Zenith Distance (*q.v.*, page 124) (or the observer's distance from the spot on the Earth vertically below the heavenly body) alter continually. In order, therefore, to calculate the observer's Azimuth and Distance from this spot, vertically below the heavenly body, and also to ascertain the Apparent Place of the heavenly body, the exact time of the observation must be noted.

The quantities required to ascertain the Apparent Place of a heavenly body and the observer's Azimuth and Distance from the spot on the Earth's surface vertically below the body will now be briefly investigated.

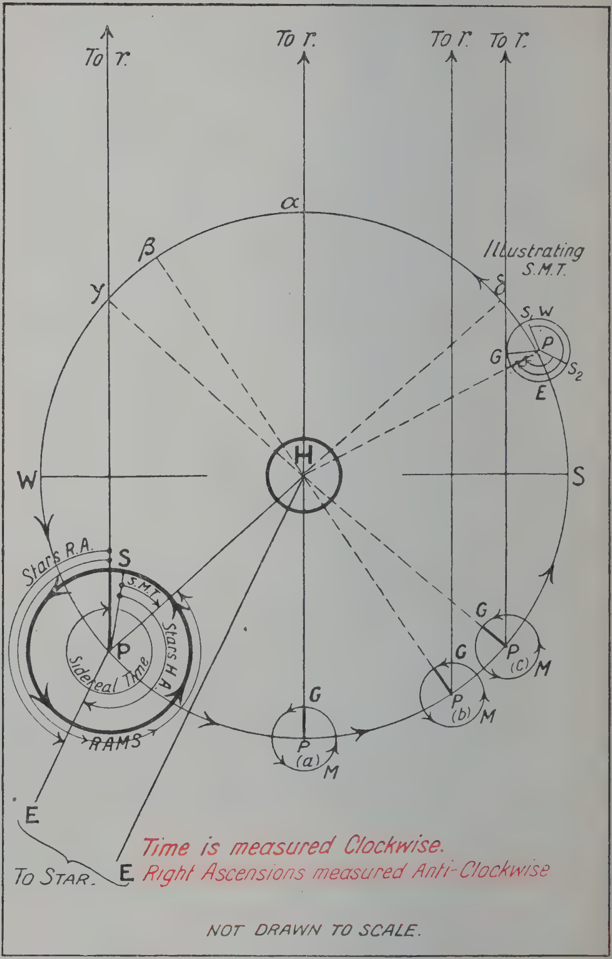

To ♈.
To ♈.
To ♈.
To ♈.
α
β
γ
δ
Illustrating
S.M.T.
S, W
P
G
S2
E
H
W
S
Stars R.A.
S
S.M.T.
P
Sidereal Time
Stars H.A.
RAMS
G
P
(a)
M
G
P
(b)
M
G
P
(c)
M
E
To Star.
E
Time is measured Clockwise.
Right Ascensions measured Anti-Clockwise
NOT DRAWN TO SCALE.

Fig. 15.

Data required for Calculating the Apparent Place of a Heavenly Body and the True Bearing and Distance of an Observer

(1) Time and the Hour Angle of the Sun

A clear conception must be obtained of what is meant by Time, and of the three methods by which Time is measured, viz. :—

(*a*) Sidereal Time (S.T.) and a Sidereal Day, measured with reference to an infinitely distant point.
(*b*) Mean Solar Time (M.S.T.) and a Mean Solar Day, measured with reference to the Mean Sun.
(*c*) Apparent Solar Time (A.S.T.) and an Apparent Solar Day, measured with reference to the True Sun.

and also of the quantities associated with the above, viz. :—

(*d*) Equation of Time, or difference between Mean Solar and Apparent Solar Time.
(*e*) Sidereal Year, Mean Solar Year, and Calendar.
(*f*) Right Ascension of the Mean Sun (R.A.M.S.).
(*g*) Right Ascension of the Moon, Planets, or Stars (R.A.).

All these quantities are measured by the angles between the planes of Great Circles called Hour Circles.

Hour Circles are half Great Circles (arcs 180°) joining the Celestial Poles. As the Celestial Poles are on the prolongation of the Earth's axis, the planes of Hour Circles also pass through the Terrestrial Poles. Hour Circles are also called Meridians.

The Meridian of a place is the Hour Circle that passes through the place.

The Equinoctial is that Great Circle whose axis passes through the Celestial Poles.

The plane of the Equinoctial cuts the planes of all Hour Circles at right angles, and coincides with the plane of the Earth's equator.

The Hour Angle of a heavenly body is the angle between the plane of the meridian of the place of the observer and the Hour Circle passing through the heavenly body.

Hour Angles are measured from zero at the meridian of the observer in a direction westerly, through 360° or 24 hours.

Graphic Representation of Time

Let an observer be situated at the North Celestial Pole, *i.e.* near the Pole Star. Fig. 15 represents what he will be assumed to view, viz. the Sun (H), around which an imaginary body, M, called the "Mean Earth" is revolving, in a true circle with centre at the centre of H, at a constant velocity, in a direction against the hands of a watch or anticlockwise, as is indicated by the arrows.

The plane of the Mean Earth's equator and of the equinoctial is represented by the plane of the paper.

P represents the pole of the Earth the observer views, *i.e.* the North Pole.

The Mean Earth will further be assumed to be revolving on its axis (through P) also in an anticlockwise direction, as shown by the arrows.

It should be noted that the direction of the Earth's orbital revolution, *i.e.* its motion round H, and its diurnal revolution round P, is in each case anticlockwise.

That the direction of the Earth's diurnal revolution round P is anticlockwise may be seen by an observer lying on his back with his head towards the North. The Sun is then observed to move from left to right, or from East to West. As, however, the Sun is stationary, it is in reality the observer that is moving from right to left or anticlockwise, from West to East.

To an observer at the South Celestial Pole all these motions will of course be in the reverse direction, *i.e.* the Earth's orbital revolution round the Sun and its axial revolution will both appear to such an observer in a clockwise direction.

These above assumed positions of the Sun and Mean Earth and the assumed motions of the Mean Earth are the bases on which Sidereal Time and Mean Solar Time are determined and measured, in order that regular and constant measures of Time may be established.

(*a*) Sidereal Time and the Sidereal Day

Let PG (fig. 15)—the Meridian or Hour Circle of Greenwich—pass through (H) the Sun when the Mean Earth is at (*a*), and cut the orbit on the opposite side at (α)—(α) being in line with an infinitely distant point (Υ) called the First Point of Aries.

Let PG then revolve through 360°, during which revolution the Mean Earth moves from (*a*) to (*b*).

The time taken by the Mean Earth to move from (*a*) to (*b*) is called a Sidereal Day.

In a Sidereal Day a meridian revolves through 360°.

A Sidereal Day is divided into 24 equal parts called Sidereal Hours, in each of which a meridian turns through 15°.

The Sidereal Time at any place at any instant is the angle between the plane of the Meridian of that place (measured in a clockwise or right-handed direction) and the plane of the Meridian of the First Point of Aries (Υ).

Now, PG at (*a*) is parallel to PG at (*b*), and in both positions PG points to Υ, as Υ is infinitely distant. For wherever the Mean Earth is situated on its orbit, the planes of all Hour Circles passing through the Mean Earth and Υ are parallel.

Now, an Hour Circle passing through the Mean Earth (M) and the Sun (H) sweeps through an arc $\alpha\beta = 58' \ 58{\cdot}65''$ as M moves from (*a*) to (*b*), *i.e.* it sweeps through this arc in 24 Sidereal Hours. For it has been found by observation that the time that elapses from when the Earth leaves the point (*a*) on its orbit and returns there again is 366 Sidereal Days 5 Sidereal Hours 48 Sidereal Minutes 42·67 Sidereal Seconds.

Hence in one Sidereal Day, by division, the arc *ab* or $\alpha\beta$ is $58' \ 58{\cdot}65''$.

Further, if the Hour Circle PG revolves from (*a*), where it is in line with H, to (*b*), where it is in line with ♈, it has revolved through 360°.

If PG continues to revolve till it next points to H, it will move on to the position (*c*).

The Meridian PG will revolve through the additional angle ♈ $P\gamma = 59' \ 8{\cdot}37''$, or the total revolution of PG in moving from in line with H to next in line with H is $360° \ 59' \ 8{\cdot}37''$.

The angle $\alpha H\gamma$ or *a*H*c* or ♈ $P\gamma$ is found by observation to be $59' \ 8{\cdot}37''$, as PG will revolve to point to H $365\frac{1}{4}$ times before the Earth returns to (*a*).

(*b*) Mean Solar Time and the Mean Solar Day

Let PG (fig. 15)—the Meridian or Hour Circle of Greenwich—pass through (H) the Sun when the Mean Earth is at (*a*).

Let PG revolve until it again passes through H, during which period the Mean Earth moves from (*a*) to (*c*).

The time taken by the Mean Earth to move from (*a*) to (*c*) is called a Mean Solar Day.

In a Mean Solar Day a meridian revolves through 360° 59′ 8·37″.

A Mean Solar Day is divided into 24 equal parts called Mean Solar Hours, in each of which a meridian revolves through $15° \ 2' \ 27{\cdot}83''$.

The Mean Solar Time at any place at any instant is the angle between the plane of the meridian of that place (measured in a clockwise or right-handed direction) and the plane of the meridian passing through the Sun (H).

When the Mean Earth is at (*c*), if PG is produced through H to cut the orbit at γ, the arc $\alpha\gamma$ and the angles $\alpha H\gamma$ or *a*H*c* are each equal to $59' \ 8{\cdot}37''$.

Now, an Hour Circle passing through the Mean Earth (M) and the Sun (H) sweeps through the arc $\alpha\gamma$ or $59' \ 8{\cdot}37''$ in 24 Mean Solar Hours, or $2' \ 27{\cdot}83''$ per Mean Solar Hour, in an anticlockwise direction.

Again, the axial spinning of the Earth revolves a meridian $360° \ 59' \ 8{\cdot}37''$ in 24 M.S. Hours, or $15° \ 2' \ 27{\cdot}83''$ per M.S. Hour, also in a direction anticlockwise.

Thus we have the meridian of a place revolving at $15° \ 2' \ 27{\cdot}83''$

per M.S. Hour being followed by the Hour Circle of the Sun (*i.e.* the Hour Circle MH) at 2′ 27·83″ per M.S. Hour.

Therefore the meridian of a place is moving away from the Hour Circle of the Sun (MH) at a relative angular velocity of 15° per M.S. Hour in a direction anticlockwise.

Mean Solar Time is therefore also the Hour Angle of the Sun, for it can be converted into arc at 1 hour per 15°.

If PG is the Meridian of Greenwich, this angle GPH, the Hour Angle of the Sun, is called Greenwich Mean Time or G.M.T., and is measured clockwise through 360° or 24 hours from zero at G.

Conversion of Sidereal Time to Mean Solar Time and vice versa

It has been shown that any meridian revolves in a—

Sidereal Day through 360° 0′ 0″ and in a Sidereal Hour through 15° 0′ 0″.

Mean Solar Day through 360° 59′ 8·37″ and in a Mean Solar Hour through 15° 2′ 27·83″.

Hence if a meridian revolves through any given angle, *e.g.* 30°, the time taken as measured in Sidereal Time is longer than the time taken as measured in Mean Solar Time. The proportion will be—

$$\frac{\text{Sidereal Time Interval}}{\text{Mean Solar Time Interval}} \text{ is in the ratio } \frac{15^\circ\ 0'\ 0''}{15^\circ\ 2'\ 27{\cdot}83''}$$

or thus—

A Sidereal Time Interval multiplied by ·99727 gives the equivalent Mean Solar Interval.

A Mean Solar Time Interval multiplied by 1·00274 gives the equivalent Sidereal Interval.

Page 154 of the Nautical Almanac converts Mean Solar Intervals to Sidereal Intervals, and conversely converts Sidereal Intervals to Mean Solar Intevals.

Quick Mental Method of converting Equivalent Intervals of Mean Solar Time to Sidereal Time and vice versa

This method is amply accurate for all purposes except perhaps in working sights for rating chronometers.

(*a*) Express the Sidereal or Mean Solar Time interval in decimals of an hour.

(*b*) This result multiplied by 10 (*i.e.* shift the decimal point one place to the right) gives the correction in seconds of time.

(*c*) Subtract the correction from Sidereal Time to obtain equivalent Mean Solar Time.
Add the correction to Mean Solar Time to obtain equivalent Sidereal Time.

(*d*) For greater accuracy, decrease the correction by 1 second for every seven hours of Sidereal or Mean Solar Time.

EXAMPLE.—Convert 17 hrs. 36 mins. 27 secs. Sidereal Time into Mean Solar Time.

Correction $= (17 \cdot 6 \times 10)$ secs. $- 3 \cdot 5$ secs. (for accuracy) $= 173 \cdot 5$ secs.

$\therefore$ Mean Solar Time Interval $= 17$ hrs. 33 mins. 33·5 secs.

EXAMPLE.—Convert 14 hrs. 57 mins. 33 secs. Mean Solar Time into Sidereal Time.

Correction $= (14 \cdot 95 \times 10)$ secs. $- 2$ secs. (for accuracy) $= 147 \cdot 5$ secs.

$\therefore$ Sidereal Time Interval $= 15$ hrs. 0 mins. 0·5 secs.

Ship Mean Time (S.M.T.)

Let PS (fig. 15) be the Meridian of a place S, then SPH is the Hour Angle of the Sun or S.M.T. at S. The S.M.T. is measured clockwise from zero at S through 360° or 24 hours Mean Solar Time.

Let PG be the Meridian of Greenwich, then GPS is the Longitude of S.

The Longitude is the angle between the Meridian of Greenwich and the Meridian of the place, and is measured from zero at G, east and west or anticlockwise and clockwise, through 180° or 12 hours.

If GPH, the Greenwich Mean Time, is known, the S.M.T. is found by subtracting or adding the Longitude, GPS, thus :—

If S is East of Greenwich, $GPH + GPS_2 = S_2PH$ measured clockwise = the S.M.T.

If S is West of Greenwich, $GPH - GPS_1 = S_1PH$ measured clockwise = the S.M.T.

This rule is best remembered by the couplet :—

Longitude East, Greenwich Time Least (*i.e.* G.M.T. is less than S.M.T.);

Longitude West, Greenwich Time Best (*i.e.* G.M.T. is greater than S.M.T.).

Longitude may be quickly converted from time to arc and *vice versa* thus :—

1 hour	$= 15°$ arc and	$1°$ arc	$= 4$ minutes of time.	
1 minute	$= 15'$,,	$1'$,,	$= 4$ seconds	,,
1 second	$= 15''$,,	$1''$,,	$= \frac{1}{15}$ second	,,

Civil and Astronomical Dates compared

The Civil Date commences at midnight and ends the following midnight, and this date is divided by Civil Time-keeping clocks into two periods of 12 hours.

The first 12 hours is called Ante-Meridian or A.M. time, the second 12 hours Post-Meridian or P.M. time.

The Astronomical Date commences 12 hours after the Civil Date, *i.e.* at noon or at 12 A.M. on a given date, and ends at the following noon.

Hence Civil Date, A.M. time, is one day more but 12 hours less than Astronomical time; and Civil Date, P.M. time, is both day and time the same as Astronomical time.

Therefore, to convert Civil date and time to Astronomical date and time—

> If A.M. time, add 12 hours and put the date one day back.
> If P.M. time, make no change in time or date.

Thus, 20th June 8 A.M. Civil time is 19th June 20 hours Astronomical time; and 20th June 8 P.M. Civil time is 20th June 8 hours Astronomical time.

Apparent Solar Time or Hour Angle of the True Sun

Hitherto a body called the Mean Earth has been imagined revolving round the Sun in a perfect circle, at a uniform speed, with a path in the plane of the Equinoctial or Equator.

This supposition is necessary in order that uniform standards of time, the Sidereal and Mean Solar times and days, may be established.

What really occurs may be explained thus (fig. 16):—

In the centre is the Sun (H) with the True Earth revolving round it in an ellipse. This ellipse is called the *Ecliptic* or *Earth's Orbit,* and is shown in fig. 16 in red. The solid red curve is above the plane of the paper or above the plane of the Equinoctial, to an observer viewing it from the North Celestial Pole or Pole Star, and the dotted red curve is below this plane.

The angle between the plane of the red ellipse and the plane of the black circle, or between the planes of the Ecliptic and Equinoctial, is called the *Obliquity of the Ecliptic,* and is about $23° 27' 11''$ (1911).

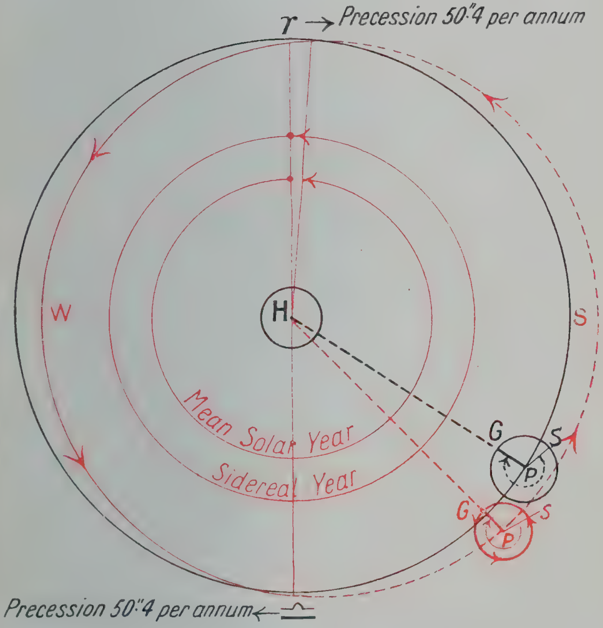
The Sun is at one of the foci of the Ecliptic, *i.e.* at that focus nearer the solid red circle.

The Earth does not move at a constant speed, but moves faster in the solid red curve.

The Earth's orbital speed is greatest at W, least at S, with a mean speed at ♈ and ♎.

The Equinoctial Points are ♈ and ♎, where the Ecliptic and

Fig. 16.


♈ → Precession 50″·4 per annum
W
S
H
Mean Solar Year
Sidereal Year
G
S
P
G
S
P
Precession 50″·4 per annum ← ♎

Equinoctial intersect, and when the Earth is at these points day and night are of equal length.

The Solstitial Points are S and W, where the Ecliptic and Equinoctial are farthest apart; S being the summer, and W the winter Solstice respectively in the Northern Hemisphere, and *vice versa* in the Southern Hemisphere.

Apparent Solar Time or the **True Sun's Hour Angle** at any instant at any place is the angle between the plane of the Meridian of the place and the plane of the Hour Circle passing through the True Earth and Sun.

This angle is measured clockwise through 24 hours or 360° from zero at the plane of the Meridian of the place, and is also called *Ship Apparent Time or S.A.T.*

Apparent Time is obtained from Mean Time by applying to the latter a correction called the "Equation of Time."

S.A.T. is the angle required for finding the Apparent Place of the Sun and its Azimuth and Zenith Distance from the observer.

Equation of Time

The Equation of Time (Eq. of T.) is a correction to convert S.M.T. to S.A.T. and *vice versa*.

The Eq. of T. at G.M. Noon (with the change per hour) is given on page I, and for every 2 hours from G.M. Noon on pages III to VI of each month in the Nautical Almanac.

The maximum change per hour is only 1·24″; consequently values of the Eq. of T. for intermediate times can be determined by inspection of the values on pages III to VI.

The Equation of Time is sometimes increasing and sometimes decreasing. It is sometimes added to, and sometimes subtracted from, S.M.T. to obtain S.A.T.

It is zero four times a year, at about −15th April, +14th June, −2nd Sept., +25th Dec.

The signs + and − above show whether it is to be added to or subtracted from S.M.T. to obtain S.A.T. between the above dates.

Its maximum values are :—

12th Feb. 14 mins. 24 secs. −M.T. 15th May 3 mins. 47 secs. +M.T.
27th July 6 mins. 20 secs. −M.T. 4th Nov. 16 mins. 22 secs. +M.T.

Years

There is a further measure of time—the Year. There are two kinds of years, viz. the Sidereal Year and the Mean Solar Year.

As already stated, in a Sidereal Day the Mean Earth moves 58′ 58·65″, and in a Mean Solar Day the Mean Earth moves 59′ 8·37″.

The Sidereal Year.—In a Sidereal Year the Earth moves 360° round the Sun (*v.* fig. 16).

In Sidereal Time the year $= 360° \div 58' \ 58{\cdot}65''$, or 366 days 6 hrs. 9 mins. 9·31 secs. Sidereal Time.

In M.S. Time the year $= 360° \div 59' \ 8{\cdot}37''$, or 365 days 6 hrs. 9 mins. 9·31 secs. Mean Solar Time.

The Mean Solar Year.—In a M.S. Year the Earth moves 359° 59′ 9·6″ round the Sun (*v.* fig. 16), for the Earth leaves and returns to ♈, and owing to "Precession" (*q.v.*, page 120) ♈ moves clockwise 50·4″ per annum to meet the Earth.

In Sidereal Time the year $= 359° \ 59' \ 96'' \div 59' \ 8{\cdot}37'' = 366$ days 5 hrs. 48 mins. 42·67 secs. Sidereal Time.

In M.S. Time the year $= 359° \ 59' \ 9{\cdot}6'' \div 59' \ 8{\cdot}37'' = 365$ days 5 hrs. 48 mins. 46 secs. Mean Solar Time.

The Calendar

A Mean Solar Year = 365·2422 Mean Solar Days,
and Four M.S. Years = 1460·9688 ,, ,,

But in four M.S. Years there are 1461 M.S. Days, one year being Leap Year.

Hence in the calendar 4 years are too long by ·0312 Mean Solar Days; or 400 years are too long by 3·12 Mean Solar Days.

This is corrected by three leap years in 400 years having only 365 days.

The three leap years with only 365 days are those three centuries not exactly divisible by 400.

Similarly, one additional day must be dropped in 4000 years, and two additional in 40,000 years.

(2) Right Ascension and Hour Angles of the Moon, Planets, and Stars

Right Ascension (R.A.) of a heavenly body is the angle between the plane of the Hour Circle passing through the First Point of Aries (♈) and the plane of the Hour Circle passing through the body. R.A. is measured from zero at ♈, in a direction anticlockwise, through 24 hours, each hour corresponding to an angular difference of 15° (*v.* fig. 15).

(As ♈ is infinitely distant, the planes of all hour circles passing through ♈ and the Earth, in any position in its orbit, are all parallel.)

Right Ascension of the Mean Sun

Right Ascension of the Mean Sun, and the Sidereal Time, at Greenwich Mean Noon are given on page I of each month in the Nautical Almanac. This is the same as the Right Ascension of the Sun from the Mean Earth, or the Sidereal Time at Greenwich on the Mean Earth at Greenwich Mean Noon, employing the term " Mean Earth " as before.

Now, referring to fig. 15, if, when the Mean Earth is at (a), the meridian of Greenwich (PG) is pointing to the Sun (H) and to ♈, the R.A.M.S. and Sidereal Time at G.M. Noon are zero. Next time PG points to H the hour circle PH has swept the arc $\alpha\gamma = 59' \ 8{\cdot}37''$ or 3 mins. 56·558 secs. (*v.* page 107).

The R.A.M.S. and the Sidereal Time at G.M. Noon therefore increase by this amount, viz. 3 mins. 56·558 secs. per M.S. Day, or 9·8554 secs. per M.S. Hour.

To obtain, therefore, the R.A.M.S. or Sidereal Time at any time after G.M. Noon, these must be augmented at this rate. For example, one Mean Solar Hour after G.M. Noon on a day when R.A.M.S. and Sidereal Time are zero at noon, the R.A.M.S. has increased 0 hrs. 0 mins. 9·8554 secs. The Sidereal Time is, however, 1 hr. 0 mins. 9·8554 secs., and so on for each hour.

At Noon the next day the R.A.M.S. is 0 hrs. 3 mins. 56·558 secs., while the Sidereal Time is 24 hrs. 3 mins. 56·558 secs. The hours being omitted, the R.A. and Sidereal Time are tabulated as the same amount.

A table for augmenting the R.A.M.S. and Sidereal Time is given on page I of each month in the Nautical Almanac. This can also be done mentally as given on page 108.

To find Sidereal Time at any Time at any Place

From fig. 15 it is seen that as the Earth moves anticlockwise through $15° \ 2' \ 27{\cdot}83''$, 1 hr. Mean Solar Time, or 1 hr. 0 mins. 9·855 secs. Sidereal Time, elapses.

If, therefore, to the Sidereal Time at the preceding Mean Noon, Sidereal Time at the rate of 1 hr. 0 mins. 9·8554 secs. is added, Sidereal Time is obtained.

For example, find the Sidereal Time at 4 P.M. on 21st April 1915 at places 45° E. and W.

	h.	m.	s.		h.	m.	s.
Mean Time at 45 E.	4	0	0	at 45 W.	4	0	0
Longitude	3	0	0 E.		3	0	0 W.
G.M.T.	1	0	0		7	0	0
Augmentation for G.M.T.	0	0	9·8554		0	1	8·9878
Corresponding Sidereal Interval	1	0	9·8554		7	1	8·9878
Sidereal Time at G.M. Noon	1	53	54·3		1	53	54·3
Sidereal Time at Greenwich	2	54	4·1554		8	55	3·2878
Longitude	3	0	0		3	0	0
Local Sidereal Time at 45 E.	5	54	4·1554	at 45 W.	5	55	3·2878

Sidereal Time at G.M. Noon and Mean Time of Transit of ♈

On page I of each month in the Nautical Almanac Sidereal Time at G.M. Noon is given.

On page II of each month in the Nautical Almanac G.M.T. of Transit of 1st Point of Aries is given.

Referring to fig. 15, suppose two clocks, one keeping Sidereal and the other keeping Mean Solar Time, start simultaneously at 0 hrs. when the Mean Earth is at (*a*).

When the Mean Earth arrives at (*b*) the clocks will show as follows :—

The Sidereal clock, having turned 24 hrs., will again show 0 hrs.

The M.S. clock will show 23 hrs. 56 mins. 4·08 secs., the equivalent M.S. Time, and will then be showing G.M.T. of transit of ♈, as PG will be pointing to ♈.

Now, while the Mean Earth moves from (*a*) to (*b*) an Hour Circle through the Mean Earth and the Sun (H) moves over an arc ♈$\beta = 58' \; 58{\cdot}8''$ or 3 mins. 55·91 secs.

Hence G.M.T. of Transit of ♈ will be earlier daily by 3 mins. 55·91 secs., as the Almanac shows.

When the Mean Earth arrives at (*c*) the clocks will show as follows :—

The M.S. clock, having turned 24 hrs., will again show 0 hrs.

The Sidereal clock will show 0 hrs. 3 mins. 56·558 secs., and will then be showing the Sidereal Time at G.M. Noon.

Now, while the Earth moves from (*a*) to (*c*) an Hour Circle through the Mean Earth and the Sun (H) moves over an arc $\alpha\gamma = 59' \; 8{\cdot}37''$ or 3 mins. 56·558 secs.

Hence Sidereal Time at G.M. Noon will be later by 3 mins. 56·558 secs. daily, as the Almanac shows.

The Double Transit of the 1st Point of Aries.

It will be seen that during the M.S. day, when the Mean Earth moves from (*a*) to (*c*), the Meridian of Greenwich (PG) passes in line with ♈ twice, viz. at (*a*) and (*b*).

This occurs annually about the 25th March, when both times of Transit in small figures are given.

Moon's Right Ascension

The Moon's R.A. for every 2 hours from G.M. Noon is given on pages VII to X inclusive of each month in the Nautical Almanac. The increase in 2 hours (in seconds of time) is given on the right between the tabulated R.A.'s. This increase varies between 218 and 343 seconds in 2 hours, or between 1·6 and 2·7 seconds per minute.

As the Moon's R.A. increases rapidly, it should be corrected for an accurate G.M.T.

The value of the R.A. at an intermediate G.M.T. is readily obtained by the Table of Proportional Parts, pages 170 to 175, Nautical Almanac, or by slide rule.

Using the Table of Proportional Parts.—Enter table with difference in 2 hours at top of page and the interval from the nearest hour of G.M.T. at the left-hand side, and take the corresponding correction.

Using the Slide Rule.—Set 2 on cursor over interval from nearest hour of G.M.T. expressed in decimals of 1 hour. Opposite figure on cursor representing increase in 2 hours read the correction.

Planets' Right Ascensions

The R.A.'s of Venus, Mars, Jupiter, Saturn at G.M. Noon are given on pages XI and XII of each month in the Nautical Almanac. The variation in 24 hours (in seconds of time) is given on the right between the tabulated R.A.'s.

The value of the R.A. at an intermediate G.M.T. is readily obtained by the Table of Proportional Parts, pages 170 to 175, Nautical Almanac, or by slide rule.

Using Table of Proportional Parts.—Enter table with difference in 24 hours at the top of the page and the G.M.T. at the right-hand side of the table, and take out the corresponding correction.

Using the Slide Rule.—Set 24 on cursor over G.M.T. in hours and decimals of an hour. Opposite figure on cursor representing the variation in 24 hours read the correction.

Planets' R.A.'s may increase or decrease, and care must be taken in applying the correction.

All planets, like the Earth, revolve anticlockwise round the Sun; the orbit of Venus is within the Earth's orbit, and the orbits of Mars, Jupiter, Saturn, are without that of the Earth

Hence, referring to fig. 15, it is readily seen that an Hour Circle passing through the Earth and a Planet may move clockwise or anticlockwise, this depending on, the relative speeds of the Earth and Planet, the position of the Earth and the Planet on their orbits, and on whether the Planet's orbit is within or without that of the Earth.

Stars' Right Ascensions

The R.A.'s of the Apparent Places of 160 stars of magnitude 3·0 and upwards for every 90 days are given on pages 146 to 153 inclusive of the Nautical Almanac.

The values for intermediate days can be taken out by inspection.

Stars are so distant that any one of them is on the same Hour Circle wherever the Earth may be in its orbit.

The R.A. of a Star would therefore always be the same were it not affected by the Star's Proper Motion, by Aberration, Precession, and Nutation.

Finding the Hour Angles of Moon, Stars, and Planets

In fig. 15, let PE or HE be the Hour Circle of a Star E, E being so distant that PE and HE are parallel; then to an observer whose Meridian is PE—

The angle	SPE	measured	clockwise	from zero at	S	=	Star's H.A.
,, ,,	ΥPE	,,	anticlockwise	,, ,,	Υ	=	Star's R.A.
,, ,,	ΥPH	,,	anticlockwise	,, ,,	Υ	=	R.A.M.S.
,, ,,	SPH	,,	clockwise	,, ,,	S	=	S.M.T.

Now, angle SPH + angle ΥPH = S.M.T. + R.A.M.S. = angle SPΥ = H.A. of Υ or Sidereal Time.

The Sidereal Time or R.A.M.S. at G.M. Noon is given on page I of the month in the Nautical Almanac, and to obtain the R.A.M.S. required in the above equation, it must be augmented for the G.M.T. at 10 seconds per hour, or by the table on the same page.

The G.M.T. is found from Deck Watch and Chronometer when sights are taken.

With the Ship Sidereal Time (S.S.T.), viz. the angle SPΥ, thus obtained we have—

$$\text{Hour Angle of Star} = \text{angle SPE} = \text{angle SP}\Upsilon - \text{angle }\Upsilon\text{PE}$$
$$= \text{S.S.T.} - \text{Star's R.A.}$$

If the Hour Angle of the Moon or of a Planet is required, the proof and procedure are the same as above, except that the Moon's or Planet's R.A. must be corrected for G.M.T. as already set forth.

This angle, the H.A. of the Moon, a Planet, or Star, called the Westerly Hour Angle (W.H.A.)—for it is measured clockwise,—is the angle required in calculating the Azimuth and Distance of the point on the Earth where the body is overhead.

Examples of thus finding the W.H.A. are found in the worked examples.

(3) Declination and Polar Distance

The Declination of a heavenly body is the arc of the Hour Circle, passing through the body, intercepted between the Equinoctial and the centre of the body.

Declination is measured N. or S. from zero at the Equinoctial to 90°, and is marked N. or S. according to whether the body is N. or S. of the Equinoctial.

The Polar Distance of a heavenly body is the arc of the Hour Circle, passing through the body, intercepted between the Celestial Pole of the observer and the centre of the body.

Polar Distance = (90° ± the Declination).

Declination Parallels are small circles whose planes are parallel to the plane of the Equator.

Sun's Declination

The Sun's Apparent Declination at G.M. Noon and variation in 1 hour are given on page I, and for every 2 hours from G.M. Noon on pages III to VI, of each month in the Nautical Almanac.

The corrected Declination for intermediate times can be estimated mentally.

The Declination is sometimes increasing and sometimes decreasing, and it changes from N. to S. and from S. to N. at about 21st March and 23rd September, thus :—

−S. 21st March N. + N. 22nd June N. − N. 23rd Sept. S. + S. 23rd Dec.

The signs + or − show where the Declination is increasing and decreasing respectively, and N. and S. whether the Declination is N. or S. respectively between the above dates.

Moon's Declination

The Moon's Declination for every 2 hours from G.M. Noon is given on pages VII to X inclusive of each month in the Nautical Almanac. The change in 2 hours (in minutes of arc, *the last figure representing tenths*) is given on the right between the tabulated Declinations.

This change varies between 0′ and 33·6′ in 2 hours, or between 0′ and ·28′ per minute.

As the Moon's Declination varies rapidly, it should be corrected for an accurate G.M.T.

The value of the Declination at an intermediate G.M.T. is readily obtained by the Table of Proportional Parts, pages 170 to 175, Nautical Almanac, or by slide rule.

Using the Table of Proportional Parts.—Enter table with difference in 2 hours at top of page and the interval from the nearest hour of G.M.T. at the left-hand side, and take the corresponding correction.

Using the Slide Rule.—Set 2 on cursor over interval from nearest hour of G.M.T. expressed in decimals of 1 hour. Opposite figure on cursor representing variation in 2 hours read the correction.

The Moon's Orbit

The Moon completes an orbit round the Earth in about 27 days 4 hours.

The plane of this orbit makes a maximum angle of about $5\frac{1}{2}°$ with the plane of the Ecliptic, first on one side and then on the other.

The inclination of the Moon's orbit to the Ecliptic changes from a maximum on one side to a maximum on the other side in about 6798 days or nearly 19 years.

Midway between these extremes the Moon's orbit coincides with the plane of the Ecliptic, and the Lunar *Solstitial* Declination will have a maximum of 29° N. or S. and a minimum of 18° N. or S. every 19 years, *i.e.* the obliquity of the Ecliptic + or − the inclination of the Moon's orbit, or $23° \ 27' \pm 5° \ 30'$.

The Moon's orbit is an ellipse in one focus of which the Earth is situated.

The Moon is said to be in "Perigee" when nearest the Earth, and in "Apogee" when furthest from the Earth.

Planets' Declinations

The Declinations of Venus, Mars, Jupiter, Saturn at G.M. Noon are given on pages XI and XII of each month in the Nautical Almanac. The change in 24 hours (in minutes of arc, *the last figure representing tenths*) is given on the right between the tabulated Declinations.

The value of the Declination at an intermediate G.M.T. is readily obtained by the Table of Proportional Parts, pages 170 to 175, Nautical Almanac, or by slide rule.

Using the Table of Proportional Parts.—Enter table with difference in 24 hours at the top of the page and the G.M.T. at the right-hand side of the table, and take out the corresponding correction.

Using the Slide Rule.—Set 24 on cursor over G.M.T. in hours and decimals of an hour. Opposite figure on cursor representing variation in 24 hours read the correction.

Stars' Declinations

The Declinations of the Apparent Places of 160 stars of magnitude 3·0 and upwards for every 90 days is given on pages 146 to 153 inclusive of the Nautical Almanac.

The values for intermediate days can be taken out by inspection.

Stars are so distant that any one of them is on the same Declination Parallel wherever the Earth may be in its orbit.

The Declination of a Star would therefore always be the same were it not affected by the Star's Proper Motion, by Aberration, Precession, and Nutation.

(4) Remarks on the Apparent Places of Heavenly Bodies

As has been already explained, the Apparent Place of a heavenly body is determined by its Right Ascension and Declination, just as a place on the Earth is determined by its longitude and latitude.

These Apparent Places are, as already stated, affected by—

(*a*) Proper Motion of the body itself.
(*b*) Aberration of Light.
(*c*) Precession of the Equinoxes.
(*d*) Nutation of the Earth's Axis.
(*e*) The Earth's position in its orbit or the Earth's Proper Motion.

A few brief explanatory remarks on the above are given to aid a clear comprehension of Nautical Astronomy.

(*a*) **Proper Motion** is the motion a heavenly body itself has in space, *e.g.* the Earth's and Planets' orbital motion round the Sun and the Moon's orbital motion round the Earth. In addition, the Sun also has a proper motion in space, carrying with it all its planetary system, so the proper motion of any one is complex.

Proper Motion of some stars has been detected, but the effect in altering the Apparent Places is very small.

(*b*) **Aberration** is the apparent displacement of a heavenly body due to the relative velocity of the speed of light from the body, and the Earth's orbital and rotational speed.

The maximum Aberration due to the Earth's orbital speed is 10·2″, and to the Earth's rotational speed ·15″.

The result of Aberration is to incline the object end of a telescope forward in the direction of the Earth's motion.

Aberration does not depend on distance, but solely on the speeds of light and of the Earth; consequently all bodies are equally affected by it.

Aberration is the direction of the resultant velocity of the velocities of light and of the observer, and it is in the direction of this resultant velocity that a heavenly body appears to an observer.

The phenomenon of Aberration may be explained as follows :—

If a ship is stationary, or if she steams directly to or directly from the wind, but in the latter case slower than the wind, a wind vane will in each case point in the true direction of the wind.

If, however, a ship steams at right angles to the wind, the wind vane will point ahead of the true direction of the wind. This deflection ahead of the true direction increases as the speed of the ship increases, and decreases as the angle between the ship's course and the wind decreases.

Similarly, when the Earth moves directly to or from a heavenly body, Aberration due to orbital speed is zero, and an observer's telescope points directly towards the True Place of the heavenly body.

When, however, the Earth moves at right angles to the direction of a heavenly body, Aberration due to orbital speed is maximum, and an observer's telescope points ahead of the True Place of the heavenly body.

Hence at two points on the Earth's orbit the Aberration of any body due to the orbital speed is zero, and at two it is a maximum.

At maximum points an observer's telescope may point 10·2″ ahead of a heavenly body, first on one side and then on the other, thus giving the body an apparent maximum displacement of 20·4″ in the course of a year.

A similar explanation applies to the Earth's rotational speed, the maximum displacement from this cause being ·15″, first on one side and then on the other, giving a maximum displacement of ·3″ in 24 hours.

Thus it is not strictly accurate to say that the planes of all Hour Circles through the Apparent Places of Stars are all parallel wherever the Earth may be in its orbit, as these Hour Circle Planes are affected by Aberration.

(*c*) **Precession** is the slow movement of the Equinoctial points ♈ and ♎ in a clockwise direction round the Equinoctial as viewed from the North Celestial Pole (*v.* fig. 16).

It has been assumed hitherto that the Earth's axis always points to the same infinitely distant point in space near the Pole Star. This is not so.

The point to which the Earth's axis points, moves in space round a large circle, whose diameter subtends an angle of about 47° from the Earth.

This motion of the Earth's axis is termed Precession, and it takes about 25,866 years to complete this circle, the point to which the N. Pole is directed moving round clockwise.

Precession may be pictured by two hoops (*v.* fig. 16), one representing the Ecliptic and the other the Equinoctial, whose planes intersect on the line ♈ ♎ at an angle of 23° 27′ 3·11″. The hoop in red, the Ecliptic, is stationary; the other, in black, moves round it, always maintaining the angle 23° 27′ 3·11″ (nearly) between their planes, and consequently the common diameter ♈ ♎ moves clockwise 50·4″ per annum, completing a circuit in 25,866 years.

Consequently, the axis of the Equinoctial, which is the axis of the Earth, describes a large circle in space whose radius subtends the obliquity of the Ecliptic, viz. 23° 27′ 3·11″ nearly, or whose diameter subtends double this angle, *i.e.* 47° nearly.

The Ecliptic Plane appears stationary in space, the Equinoctial Plane changing as above.

Precession is mainly due to the Sun's attraction on the Earth's equatorial protuberances.

(*d*) **Nutation** is the nodding of the Earth's axis due to the Moon's attraction on the Earth's equatorial protuberances. In a similar manner to Precession, Nutation should cause the Earth's axis to

describe in space a small circle in the course of 19 years. The combined effect of Precession and Nutation causes the Earth's axis to describe a wavy circle in space, 19 years elapsing from crest to crest of the waves, the circle being completed in 25,866 years.

Both Precession and Nutation slightly affect the obliquity of the Ecliptic, or, more accurately, the position of the plane of the Equinoctial in space.

As R.A.'s and Declinations are measured along or from the Equinoctial, these changes affect the R.A.'s and Declinations of all bodies.

(*e*) **Earth's Orbital Motion** in the plane of the Ecliptic alters the Apparent Positions of the nearer heavenly bodies, Sun, Moon, and Planets, but stars are not sensibly affected.

In the case of the Sun, the Earth's orbital motion alters the Sun's R.A. 360° in a year, and changes the Sun's Declination from N. to S.

The Moon's and Planets' R.A.'s and Declinations are also altered by the Earth's orbital motion as well as by their own. The Moon's R.A. always increases; the Planets' R.A.'s sometimes increase and sometimes decrease, though the orbital motion of all is anti-clockwise.

(5) The Assumed Latitude and Longitude

Date and Time, Right Ascension and Declination, determine the Apparent Place of a heavenly body. Date and Time also determine the position of the Earth in its orbit and the position of its surface in its axial rotation. Hence the spot on the Earth's surface where the heavenly body is exactly overhead at the given Date and Time can be found.

The Latitude and Longitude of the estimated position of the observer is taken, and the Azimuth and Distance from this place, of that spot where the observed heavenly body is exactly overhead at the given instant, is calculated.

This Latitude and Longitude is called the "Assumed Latitude and Longitude."

The Assumed Latitude is required for the calculations.

The Assumed Longitude is required for finding the S.A.T. in Sun observations and the W.H.A. in the case of other heavenly bodies.

The Assumed Longitude is also required to find the G.M.T. in order to correct the data given in the Nautical Almanac, as already shown.

It might at first appear that, by using an Assumed Latitude and Longitude for the above purposes, errors would arise and the final position thereby determined would be erroneous; and further that, as the Longitude is not exactly known, chronometer errors, and errors in correcting the Eq. of T., R.A., and Decl., would be important.

This, however, is not the case, as the calculation determines the exact Azimuth and Distance from the assumed Latitude and Longitude of the spot on the Earth where the heavenly body is exactly overhead at the instant.

The observer at the same instant, by measuring the altitude of the heavenly body, ascertains exactly how much he is nearer to or further from the spot where the heavenly body is overhead, and thereby corrects with accuracy the assumed position.

Thus it is clear that every accuracy in ascertaining the Azimuth and Distance from the assumed position is important.

(6) Data determined from the Assumed Position (by Calculation or by Tables)

(a) The Azimuth

The Zenith is that point in the Celestial Sphere vertically above the observer.

The Nadir is that point in the Celestial Sphere vertically below the observer.

Azimuth Circles are half Great Circles (arcs 180°) joining the Zenith and Nadir.

The Horizon is that great circle whose axis is the line joining the Zenith and Nadir. The plane of the Horizon cuts the planes of all Azimuth Circles at right angles.

The Azimuth of a heavenly body is the angle between the plane of the Azimuth Circle passing through the Zenith, the North Celestial Pole, and Nadir; and the Azimuth Circle passing through the body.

Azimuth is measured clockwise through 360°, from zero at the plane of the Azimuth Circle passing through the North Celestial Pole. This secures uniformity with compasses graduated from 0 to 360°, simplicity is introduced, and errors are avoided, for it may be remembered Azimuths will lie between the limits :—

	Rising Bodies.	Transit Bearing.		Setting Bodies.
		Below Pole.	Above Pole.	
North Hemisphere	Azimuth increasing clockwise from 0 to 180°.	0°	180°	Azimuth increasing clockwise from 180° to 360°.
South Hemisphere	Azimuth decreasing anticlockwise from 180° to 0°.	180°	0°	Azimuth decreasing anticlockwise from 360° to 180°.

With the H.A., Decl., and Latitude the Azimuth of the heavenly body is obtained by—

(a) Burdwood and Davis's Azimuth Tables.
(b) Towson's Great Circle Tables.
(c) By direct calculation.
(d) As explained in Part II., by projection or by Spherical Diagram.

In plotting Azimuths or P.L.'s on the chart, care must be taken, if using a magnetic compass on the chart, to correct the latter for the annual change of Variation.

It is desirable, when observing a heavenly body, to take its compass bearing in order that the compass error may be readily and accurately determined. This is especially desirable when the altitude is low, as the bearing is then altering rapidly.

(*b*) The Zenith Distance

The Altitude of a heavenly body is the arc of the Azimuth Circle passing through the body intercepted between the Horizon and the centre of the body.

Altitude is measured from zero at the Horizon through 90°.

The Zenith Distance of a heavenly body is the arc of the Azimuth Circle passing through the body intercepted between the Zenith of the observer and the centre of the body.

Zenith Distance = (90° − the Altitude).

Altitude Parallels are small circles whose planes are parallel to the plane of the Horizon.

Calculating the Zenith Distance

As already stated, the Zenith Distance (or the Distance of an Assumed Position from the spot on the Earth's surface where a heavenly body is overhead at a given instant) can be calculated from the body's Hour Angle, Declination, and the Latitude of the Assumed Position. The calculation is effected by means of the relation existing in any spherical triangle ABC, viz. :—

$$\text{cosine } a = \text{cosine } b \text{ cosine } c + \text{sine } b \text{ sine } c \text{ cosine A}.$$

It is applied thus :—

$$\text{cosine } z = \text{cosine } (90 - d) \text{ cosine } (90 - l) + \text{sine}(90 - d) \text{ sine } (90 - l) \text{ cosine } p,$$

where z is the Zenith Distance of the heavenly body.

d ,, Declination or $(90 \pm d)$ is the Polar Distance.

p ,, Hour Angle.

l ,, Latitude or $(90 - l)$ is the Co-latitude.

Whence $\text{cosine } z = \text{sine } d \text{ sine } l + \text{cosine } d \text{ cosine } l \text{ cosine } p$.

But $\text{cosine A} = 1 - \text{versine A}$.

Therefore

$$1 - \text{versine } z = \text{sine } d \text{ sine } l + \text{cosine } d \text{ cosine } l\ (1 - \text{versine } p),$$

or $$1 - \text{versine } z = \text{sine } d \text{ sine } l + \text{cosine } d \text{ cosine } l - \text{cosine } d \text{ cosine } l \text{ versine } p.$$

$$-\text{versine } z = -1 + \text{cosine } (l \underset{\sim}{+} d) - \text{cosine } d \text{ cosine } l \text{ versine } p.$$

Dividing by −2,

$$\text{Haversine } z = \text{Haversine } (l \underset{\sim}{+} d) - \text{cosine } d \text{ cosine } l \text{ Haversine } p.$$

Let $\text{Haversine } p \cos d \cos l = \text{Haversine } \theta.$

Then $\text{Haversine } z = \text{Haversine } (l \underset{\sim}{+} d) - \text{Haversine } \theta.$

If the Lat. and Decl. are both N. or both S., the Polar Distance is $(90 - d)$.

The above formula then becomes:

$$\text{Haversine } z = \text{Haversine } (l+d) + \text{Haversine } \theta.$$

If the Lat. and Decl. are one N. and the other S., the Polar Distance is $(90+d)$.

The formula then becomes:

$$\text{Haversine } z = \text{Haversine } (l \sim d) + \text{Haversine } \theta.$$

Hence if Lat. and Decl. are both N. or both S., add them; and if one is N. and the other S., take the difference.

These are the formulæ used and shown in the worked examples.

ERRATA

Page 124, lines 33, 35, and 37, *for* $(l \pm d)$ *read* $(l \sim d)$.
Page 125, line 2, *for* $(l+d)$ *read* $(l \sim d)$.
line 6, *for* $(l \sim d)$ *read* $(l+d)$.
line 7, *for* "add then" *read* "take their difference."
line 8, *for* "take the difference" *read* "take their sum"

(7) Data determined from the True Position (by observation), Time, Azimuth, and Zenith Distance

(*a*) The Time

Observations are generally timed by a Deck Watch.

A Deck Watch beats five times in two seconds, and a practised time-taker can take times to one-fifth of a second by counting the beats from an even second, thus: 4, 8, 2, 6, 0, and so on—*i.e.* if starting at six seconds these times are 6·4, 6·8, 7·2, 7·6, 8·0 seconds respectively.

Care should be taken by the time-taker to note the minute before and after the last observation.

The Deck Watch should be compared with the Chronometer before and after observations are taken, if possible.

The difference between Deck Watch and Chronometer, added if Deck Watch time is slow, and subtracted if Deck Watch time is fast, gives Chronometer time.

The difference between Chronometer and G.M.T., added if Chronometer time is slow, and subtracted if Chronometer time is fast, gives G.M.T.

This G.M.T. is required in finding the Hour Angles of all heavenly bodies.

Time and Sight Taking.—Some navigators depend on one careful observation; others prefer to take the mean of several. If several observations are taken and the mean used, the observations may be checked by seeing if the time intervals are nearly proportional to the altitude changes.

A good system is to put the sextant on or back 5′ or 10′ according to whether the body is rising or setting, and to call "Stop" to the time-taker to note the time when the Altitude is on. The time intervals should then be nearly equal, especially if the altitude is altering rapidly.

(*b*) The Azimuth

When an observation is taken, if the Variation and Deviation of the compass are accurately known, the Bearing of the heavenly body can be taken at the same instant, and thereby the Azimuth of the body obtained. This obviates the necessity of using Azimuth Tables or in other ways determining the Azimuth.

(*c*) The Observed Zenith Distance

In Marc St Hilaire's method of "Fixing," as will be explained, two Zenith Distances are required—

(1) The Zenith Distance from the Assumed Position. This is calculated.

(2) The Zenith Distance from the True Position. This is observed.

The difference between these two Zenith Distances is evidently the observer's distance from the Assumed Position.

The Observed Altitude is the altitude of a heavenly body measured by sextant. The whole accuracy of determining the observer's position depends on the exactitude with which the times of observation are taken, and the altitudes are measured and corrected. Too much attention cannot be bestowed on this.

The following points should be borne in mind:—

(1) Always know the sextant's error, and frequently go over the adjustments.
(2) Determine or eliminate by practice the personal error.
(3) Carefully correct the Altitude.
(4) Do not take Altitudes of less than 10°, as Dip and Refraction become uncertain.
(5) For accurate Latitudes the body should bear nearly N. or S., giving a P.L. nearly E. and W.
(6) For accurate Longitudes the body should bear nearly E. or W., giving a P.L. nearly N. and S.
(7) Use shades to prevent the Sun being too bright and thereby causing "Irradiation."
(8) Take the Moon, Planets, or Stars at twilight if possible to get a good horizon.
(9) Use highest power telescope for Sun sights, as magnification is important and loss of light immaterial.
(10) Use lowest power telescope for Moon, Planets, or Stars, particularly stars, as stars will not magnify, and large field without loss of light on the horizon is necessary.
(11) See there is enough tangent screw motion for the whole set of sights.
(12) If time permits, take the Index Error before and after observing.

The Observed Altitudes of heavenly bodies must be corrected for—

(1) Dip of the Sea Horizon. There is no dip when using an artificial horizon.
(2) Semidiameter of the body. There is no S.D. for Stars, and it is practically nil for Planets.
(3) Refraction. This affects all heavenly bodies.
(4) Parallax. This does not affect Stars.

(8) Altitude Corrections

(*a*) Dip

Dip is the angle of depression of the sea horizon below a horizontal plane through the observer's eye. Dip always makes the altitude too great, and is always to be subtracted from an observed altitude.

For practical purposes, "Dip in minutes of arc = Square root of height of observer's eye in feet."

Dip may be readily taken off the slide rule, the error being under 7″ for 65 feet.

Thus: Height of eye 65 feet – $\sqrt{65} = 8{\cdot}05$ or 8′ 3″. The tables give 7′ 56″.

Dip is affected by Refraction. The effect of Refraction is to apparently raise the sea horizon and thus diminish the Dip.

In the table for Dip a deduction of about 8 per cent. is made for Refraction.

Thus: Theoretical Dip $= 1{\cdot}063\sqrt{h}$, where h is the height of the eye in feet; whereas Dip given in tables $= {\cdot}984\sqrt{h}$.

The theoretical calculation of Dip is of little value to the navigator and is omitted.

(*b*) Semidiameter (S.D.)

Semidiameter is the angle subtended at an observer's eye by the radius of a heavenly body.

If the Altitude of a heavenly body is measured between the horizon and the nearer or Lower Limb (or L.L.) the semidiameter must be added, and if measured between the further or Upper Limb (or U.L.) the semidiameter must be subtracted, to obtain in either case the Altitude of the centre of the heavenly body.

Sun's Semidiameter for each day is given on page I of the month in the Nautical Almanac. Sun's S.D. has a maximum of 16′ 18″ in January and a minimum of 15′ 45″ in July. A mean of 16′ may generally be taken. It alters so slowly that it requires no correction.

Moon's Semidiameter at G.M. Noon daily is given on page I. of the month in the Nautical Almanac, and is the S.D. subtended by the Moon from the centre of the Earth.

Moon's S.D. has a maximum of 16′ 44″ and a minimum of 14′ 43″ in the space of 14 days. Practically it is unnecessary to correct Moon's S.D., the variation being only 9″ in 24 hours.

The S.D. tabulated is the S.D. when the Moon is on the horizon and it must be augmented for the Moon's Altitude, the Moon being appreciably nearer the observer the higher the Altitude. The Augmentation of Moon's S.D. is given in Inman's Tables. Its maximum, when Moon is in the zenith, is 18″.

Planets' Semidiameter is inappreciable, and **Stars** have no Semidiameter.

(*c*) Refraction

Refraction, astronomical or atmospheric, is the apparent angular elevation of a heavenly body above its true place caused by the bending of the rays of light from the body in their passage through the Earth's atmosphere.

As Refraction increases the altitude of the body, the "Correction for Refraction" is always to be subtracted.

Refraction is greatest when a heavenly body is on the horizon, and diminishes as the altitude increases, to zero when the body is in the zenith.

Refraction is of uncertain value when a heavenly body is near the horizon; consequently altitudes should not be taken of less than 10°.

Refraction also varies with the height of the barometer and thermometer. A table is given in Inman's Tables for correcting the tabulated Refraction for height of Barometer and Thermometer.

The tabulated Refraction in Inman's Tables is for Barometer 30″ and Thermometer 60° F. or 15·5° C.

For an altitude of 10° the corrections of the tabulated Refractions are:

Barometer	28 ins. = 0′ 21″ −	Thermometer	10° F. = 0′ 28″ +
	31·5 ins. = 0′ 16″ +	,,	100° F. = 0′ 29″ −

As the altitude increases these effects decrease. The above corrections show the limiting errors, *i.e.* for $3\frac{1}{2}$ inches Barometer 0′ 37″, and for 90° Thermometer 0′ 57″.

The investigation of the formulæ for Refraction is intricate and of no practical value.

Sun's Refraction, combined with Dip (for varying heights of eye), Parallax, and semi-diameter, is given in Inman's Tables as "Sun's Correction in Altitude."

The table is entered with the "Sun's Observed Altitude" and "Height of Eye." The correction is added, except where shown with a minus sign, to the Observed Altitude.

Another table below it gives a smaller correction for "Variation of Sun's Semi-diameter."

Refraction for Moon, Planets, or Stars, combined with Dip for varying heights of eye, is given in Inman's Tables as "Star's Correction in Altitude."

The table is entered with the "Observed Altitude" of the body and the Height of Eye.

The correction is subtracted from the Observed Altitude.

(*d*) Parallax

The Parallax of a heavenly body is the angle subtended at the centre of the body by that radius of the Earth to the position of the observer.

As the data, Right Ascension and Declination, that determine the Apparent Position of a heavenly body are measured from the centre of the Earth, so also must the Altitude be corrected as if measured from the centre of the Earth.

Parallax is therefore maximum when the heavenly body is on the observer's horizon, and diminishes to zero when the body is in the observer's zenith.

Horizontal Parallax (or H.P.) is the Parallax when the body is on the Horizon.

Parallax in Altitude (or P. in A.) is the Parallax when the body is at any altitude.

The Correction for Parallax is always additive, for were an observer at the centre of the Earth the altitude of the body would be greater than if he were on the surface of the Earth, the altitude in each case being measured to the same horizon.

Sun's Parallax is given in Inman's Tables as "Parallax of Sun in Altitude." It does not exceed 0′ 9″. This table is not generally used, as the correction is applied with the Refraction (*v.* page 129).

Moon's H.P. at G.M. Noon daily is given on page II of each month in the Nautical Almanac.

This is the H.P. subtended by the Earth's Equatorial or Greatest Radius and varies between 61′ 18″ and 53′ 55″. This H.P. may vary 1′ in 24 hours and should be corrected for the G.M.T.

At other Latitudes than the Equator the Earth's Radius is less than the Equatorial Radius and the H.P. is less.

Inman's Tables give this "Reduction of H.P. for Figure of the Earth." The table is entered with,—H.P. of day and time, and the Latitude. The correction obtained is subtracted from the H.P. This is the "Reduced H.P."

Moon's Parallax in Altitude = Reduced H.P. × Cosine Altitude (this is given in Inman's Tables).

The table is entered with the "Observed Altitude of Moon's Centre" and the Reduced H.P. The correction obtained is added to the Observed Altitude of the Moon's Centre. The correction for seconds of H.P. is given at the side.

Planet's H.P. is not given in the Abridged Nautical Almanac, for it is very small in the case of Venus, Mars, Jupiter, and Saturn.

Planet's P. in A. is given in Inman's Tables for use when necessary.

Stars have no Parallax.

(9) Explanation of Fixing by Marc St Hilaire's Method

Let it be assumed that the Pole Star is situated exactly on a prolongation of the Earth's axis, then the Pole Star is exactly overhead at the North Pole.

If an observer north of the Equator measures the altitude of the Pole Star, he would measure the latitude he was in, for the altitude of the Pole at any place is equal to the latitude of that place (*v.* figs. in Part II.).

The observer then knows that—

(*a*) He is situated on a small circle called a Latitude Parallel, the Latitude of which is equal to the Altitude of the Pole Star he has measured.

(*b*) The axis of this Latitude Parallel passes through that point on the Earth's surface where the Pole Star is overhead.

(*c*) The complement of the Altitude measured, or the Zenith Distance of the Pole Star, measures the distance in nautical miles from where the Pole Star is overhead, *i.e.* the N. Pole, for Alt. of Pole = Lat. of Place; therefore Zenith Dist. of Pole Star = (90 − Lat.) or Co-Latitude.

Similarly, when an observer measures the Altitude of any heavenly body he knows—

As in (*a*), that he is situated on a small circle on the Earth's surface called an Equi-altitude Parallel, from every point of which the body will subtend the same altitude.

As in (*b*), that the axis of his Equi-altitude Parallel passes through the point on the Earth's surface where the body is exactly overhead.

As in (*c*), that the complement of the Altitude measured or the Zenith Distance of the body measures his distance in nautical miles from the point on the Earth's surface where the body is overhead.

Now Latitude Parallels are marked on a chart, and an observer can see at a glance which Latitude Parallel he is on; but Equi-altitude Parallels are not so marked.

Equi-altitude Parallels are large, especially if the Altitude of the body is not great, and small portions of their circumferences of 60 or 70 miles or more may be regarded as straight lines coinciding with the tangent to the Equi-altitude Parallel and at right angles to the Azimuth of the body from the observer.

Such portions of Equi-altitude Parallels are called Position Lines.

A Position Line (P.L.) in Ocean Navigation is a line at right angles to the Azimuth of a heavenly body and at a computed distance from that spot on the Earth's surface where the body is overhead at a given instant.

The distinction between a P.L. in Ocean Navigation and a P.L. in Coastal Navigation should be noted. In the latter case the P.L. is the bearing of a terrestrial object.

Laying off Position Lines

The navigator assumes himself to be in a certain Latitude and Longitude, and through this position draws on the chart a P.L. at right angles to the Azimuth of the heavenly body observed. This is called the Assumed P.L.

With the data, viz. H.A., Declination, and assumed Latitude, the navigator calculates the Zenith Distance of the heavenly body, or the distance of that spot on the Earth's surface where the body is in the Zenith, from the Assumed Position.

The True Zenith Distance is measured by sextant, and gives the actual distance of the observer from the spot on the Earth's surface where the body is in the Zenith.

Evidently the difference of these two Zenith Distances is the distance of the observer from the Assumed P.L. It is also evident that if the True Z.D. is less than the Calculated Z.D., the observer is on that side of the Assumed P.L. nearer the heavenly body, the converse being the case if the True Z.D. is greater than the Calculated Z.D.

Another P.L., therefore, is ruled parallel to the Assumed P.L. at a distance in nautical miles from the latter equal to the difference between the True and Calculated Z.D.'s, and on the side of the Assumed P.L. nearer the heavenly body if the Calculated Z.D. is greater, but on the further side if the True Z.D. is greater.

This Position Line is called the True P.L.

If at the same instant another True P.L. is obtained by observation of another heavenly body, the position of the observer is "Fixed" at the intersection of these two True P.L.'s.

It is not always possible to observe simultaneously two heavenly bodies, and in the interval between two observations of the same body the ship may have moved. In such case the 1st True P.L. is moved parallel to itself the distance and in the direction of the Run of the ship in the interval. The "Fix" or position of the observer is then obtained by the intersection of the 1st True P.L. (moved according to the Run of the ship) with the 2nd P.L.

Notes on Fixing by the Intersection of P.L.'s

(1) The angle between two P.L.'s should not be less than 30° to get a good cut. Therefore, if two observations of the same body are taken, the Azimuth of the body should alter at least 30° between the observations.

(2) Judge a suitable interval between two observations of the same body by the change in Azimuth and not by the time elapsing.

(3) If three bodies are observed, and all three P.L.'s intersect in the same point, the "Fix" should be very reliable.

(4) Great care should be taken, when taking more than one observation of the same body, that the Run is determined as accurately as possible. The accuracy of the Fix entirely depends on the preceding P.L. being transferred the correct amount.

(5) If two or more P.L.'s are obtained with Runs between each observation, the 1st P.L. must be moved the Run to the 2nd P.L., and the 2nd to the 3rd, and so on; or the 1st and 2nd P.L.'s may be moved their respective Runs to the 3rd P.L., when, if all three P.L.'s intersect in the same point, the "Fix" should be accurate.

(6) The most practical and useful accuracy is to fix frequently with two P.L.'s.

(7) Observations and Runs may be checked by taking two sets of sights with half an hour interval between them, and when the Azimuth of the body has altered 30° two more sets can be taken. One position may then be fixed from the 1st and 3rd P.L.'s, and another from the 2nd and 4th P.L.'s. These two fixes, being only half an hour apart, check one another.

The Advantages of Marc St Hilaire's method may be summarised as:—

(1) Positions can be determined at any time sights are taken, instead of generally at noon, as obtained under older methods. This is particularly advantageous when keeping to a Great Circle Track, and in days of high speeds, when positions alter rapidly.

(2) Fixes obtained by this method are more accurate than older methods, where the errors increased the further the Azimuth of the body was from E. or W. true.

(3) As all practical sights (except those for Latitude only) are worked in the same uniform manner, time, thought, and labour are saved.

(10) The Worked Examples and Methods of Plotting

The following five examples illustrate the working of all practical modern day sights for ascertaining the observer's Latitude and Longitude.

The plotting of the results of the working is given in diagrams 17 and 18.

Sights for Latitude only are given in Examples 6 to 12 inclusive.

Sights for rating chronometers are omitted; their practical use is rapidly disappearing with—Time Balls at Ports, Post Office facilities, and the Time Signals sent out by Wireless Telegraphy.

These sights are all worked in the same form—a practice that is very desirable in order to prevent mistakes, save labour, and attain rapidity. A definite form of sight working is also desirable for beginners as an aid to memory and to ensure the navigator can quickly recall the computation, however unpractised he may become.

A navigator with assistants can have his observations worked out by two computers, and these, if worked in the same form, are easily checked should there be any discrepancy in the results.

EXAMPLE 1.—Sun Observation for a 1st Position Line.

This observation is taken when the Sun is near the meridian, and is worked by Marc St Hilaire's method for a 1st Position Line, with a view to obtaining the observer's Latitude and Longitude in conjunction with the 2nd P.L., Example 2.

N.B.—This same observation is worked in Example 6 as an Ex Meridian Altitude to obtain the Latitude only.

The plotting of this observation is shown on diagram 17, where A is the Assumed Latitude and Longitude, the direction AB being the Sun's Azimuth.

The distance AB is the difference between the observed and calculated Zenith Distances. The red line through B is the 1st Position Line.

EXAMPLE 2.—Sun Observation for a 2nd Position Line.

The Azimuth of the Sun having altered 54°, a second observation is taken, and worked by Marc St Hilaire's method.

The plotting is shown on diagram 17.

The 1st P.L. through B is moved, parallel to itself, the Run BC.

C is in the Assumed Latitude and Longitude. The direction DC is the Sun's Azimuth. The distance CD is the difference between the observed and calculated Zenith Distances.

The red line through D is the 2nd Position Line.

E, where the 1st P.L. through C and the 2nd P.L. through D intersect, is the position of the ship at the time of the second observation.

Example 3.—Moon Observation for a 3rd Position Line.

This example illustrates the manner in which the Moon's Hour Angle is obtained.

The angle between, the Azimuth of the Sun in the previous observation and the Azimuth of the Moon in this, is 70°.

The plotting is shown on diagram 17.

The 2nd P.L. through DE is moved parallel to itself the Run EF.

F is the Assumed Latitude and Longitude. The direction FG is the Moon's Azimuth. The distance FG is the difference between the observed and calculated Zenith Distances.

The red line through G is the 3rd Position Line.

H, where the 2nd P.L. through F and the 3rd P.L. through G intersect, is the position of the ship at the time the Moon is observed.

Diagram 17 is a representation of direct plotting on a Mercator's chart, using the Latitude and Longitude scales on the framework of the chart.

Ex. 1. D.R. or Working Position.

H.M.S. Lat. 55′ 20° N. Long. 0° 25′ E. Date, 9th May 1911, P.M.

Body observed—Sun.

Greenwich Date.	Day	h.	m.	*Watch Times.* h. m. s.	*Altitudes.* ° ′ ″	*Moon's Semi-Diam.* ′ ″	*Moon's Hor. Parallax.* ′ ″
S.M.T.	May 9	0	37·5			S.D.	H.P.
Long. W.+ E.−			1·7 E.			Augn.	Redn.
Gr. Date	May 9	0	35·8			S.D.	H.P. in L. P. in A.

Correcting Data.

Mean Noon. R.A.M.S. or Equation of Time.

	h.	m.	s.
	0	3	37·92
Corrn. . .	0	0	·08
	0	3	38

Right Ascension.

	h.	m.	s.
Corrn. . .			

Mean Noon. Declination.

	°	′	″
	N. 17	7	51
Corrn. . .	0	0	24
	17	8	15

Westerly Hour Angle.

	h.	m.	s.
Watch Time,	0	32	26
Error Fast − Slow +	0	3	36 S.
G.M.T. . .	0	36	2
Long. W.− E.+		1	40 E.
S.M.T. . .	0	37	42
Eq. of T. or R.A.M.S.+	0	3	38
S.A.T. or S.S.T.	0	41	20
R.A.− . .			
W.H.A. . .			

True Bearing from Azimuth Tables.

196°.

Run 62° 30′ True. 50 miles.

Altitude.

	°	′	″
Obs. Alt. & I.E.	50	53	50
Corrns. in Alt. .	0	11	33
	51	5	23
(Semi-Diam. UL− LL+)			
Parallax in Alt.			
True Alt. . .			
Reduction to Meridian (For Ex Mer. Alts. only.)			
Mer. Alt.			
Z.D. . . .	38	54	37
Decln. (+ same) (− diff.)			
Latitude . .			

Calculating.

	h.	m.	s.
W.H.A. or S.A.T.	0	41	20
Declination,	N. 17	8	15
Latitude,	N. 55	20	0
Lat. ± Decln. .	38	11	45

Log. Hav. +	7·908998
,, Cos. +	9·980276
,, Cos. +	9·754960
Log. Hav. ⊖ (Sum) +	7·644234

Nat. Hav. ⊖	004406
,, ,, L.±D.	107049
,, ,, Z.D.±	111455
Calc. Z.D. + Mer. Z.D. −	39 0 19

Lat.+Decln. if of different names. Lat.∼Decln. if of same name.

If the Obs. Z.D. is < Calc. Z.D. the "Position Point" is towards or nearer to the Heavenly Body = 5·6′ If the Obs. Z.D. is > Calc. Z.D. the "Position Point" is away or further from the Heavenly Body.

Ex. 2. D.R. OR WORKING POSITION.

H.M.S. Lat. 55° 39′ N. Long. 1° 42′ E. Date, 9th May 1911, P.M.

Body observed—Sun.

Greenwich Date.	Day	h. m.	*Watch Times.* h. m. s.	*Altitudes.* ° ′ ″	*Moon's Semi-Diam.* ′ ″	*Moon's Hor. Parallax.* ′ ″
S.M.T.	May 9	3 37·6			S.D.	H.P.
Long. W.+ E.−		6·8 E.			Augn.	Redn.
Gr. Date	May 9	3 30·8			S.D.	H.P. in L. P. in A.

CORRECTING DATA.

R.A.M.S. or Equation of Time.	h. m. s.
	0 3 37·92
Corrn.	0 0 4·2
	0 3 42·12
Right Ascension.	h. m. s.
Corrn.	
Declination.	° ′ ″
	N. 17 7 51·1
Corrn.	0 2 21
	17 10 12

Westerly Hour Angle.	h. m. s.
Watch Time	3 26 58
Error Fast − Slow +	0 3 37 S.
G.M.T.	3 30 35
Long. W.− E.+	6 48 E.
S.M.T.	3 37 23
Eq. of T. or R.A.M.S.+	0 3 42
S.A.T. or S.S.T.	3 41 5
R.A.−	
W.H.A.	
True Bearing from Azimuth Tables.	250·3°.
Run 61° 30′ True. 67·3 miles.	

Altitude.	° ′ ″
Obs. Alt. & I.E.	33 8 30
Corrns. in Alt.	0 9 30+
(Semi-Diam.) UL− LL+)	
Parallax in Alt.	
True Alt.	33 18 0
Reductn. to Meridian (For Ex Mer. Alts. only.)	
Mer. Alt.	
Z.D.	56 42 0
Decln. (+ same) (− diff.)	
Latitude	

CALCULATING.

	h. m. s.
W.H.A. or S.A.T.	3 41 5
Declination	N. 17 10 12
Latitude	55 39 0
Lat.±Decln.	38 28 48

Log. Hav.+	9·332743
,, Cos. +	9·980198
,, Cos. +	9·751423
Log. Hav. ⊖ (Sum) +	9·064364

Nat. Hav. ⊖	115975
,, ,, L.±D.	108615
,, ,, Z.D.±	224590
Calc. Z.D.+ Mer. Z.D.−	56 34 42

{Lat.+Decln. if of different names. Lat.∼Decln. if of same name.}

If the Obs. Z.D. is < Calc. Z.D. the "Position Point" is towards or nearer to the Heavenly Body.
If the Obs. Z.D. is > Calc. Z.D. the "Position Point" is away or further from the Heavenly Body=7·3′.

Position by Plotting: Lat. 55° 37′ N. Long. 1° 56·5′ E.

Ex. 3. D.R. or Working Position.

H.M.S. Lat. 56° 9′ N. Long. 3° 42′ E. Date, 9th May 1911, P.M.

Body observed—Moon.

Greenwich Date.		*Watch Times.*	*Altitudes.*	*Moon's Semi-Diam.*	*Moon's Hor. Parallax.*
	Day h. m.	h. m. s.	° ′ ″	′ ″	′ ″
S.M.T.	May 9 7 15			S.D. 15 8	H.P. 55 30
Long. W.+ E.−	14·8 E.			Augn. 0 7·6	Redn. 0 7
Gr. Date	May 9 7 0·2			S.D. 15 15·6	H.P. in L. 55 23
					P. in A. 48 33

Correcting Data.

R.A.M.S. or Equation of Time.		*Westerly Hour Angle.*		*Altitude.*	
	h. m. s.		h. m. s.		° ′ ″
	3 4 43·63	Watch Time	6 56 37·5	Obs. Alt. & I.E.	25 57 50
Corrn.	0 1 9	Error Fast − Slow +	0 3 38	Corrns. in Alt.	5 1
	3 5 52·63	G.M.T.	7 0 15·5		25 52 49
		Long. W.− E.+	14 48 E.	(Semi-Diam. UL− LL+)	0 15 15
Right Ascension.		S.M.T.	7 15 3·5		25 37 34
	h. m. s.	Eq. of T. or R.A.M.S.+	3 5 52·63	Parallax in Alt.	0 48 33
	12 38 1·37				
Corrn.	0 0 0·55	S.A.T. or S.S.T.	10 20 56·13	True Alt.	26 26 7
	12 38 1·92	R.A.−	12 38 1·92	Reductn. to Meridian (For Ex Mer. Alts. only)	
		W.H.A.	21 42 54·21		
Declination.		*True Bearing from Azimuth Tables.*		Mer. Alt. Z.D.	63 33 53
	° ′ ″				
	S. 1 8 38		141°.	Decln. (+ same) (− diff.)	
Corrn.	0 0 4				
	1 8 42			Latitude	

Calculating.

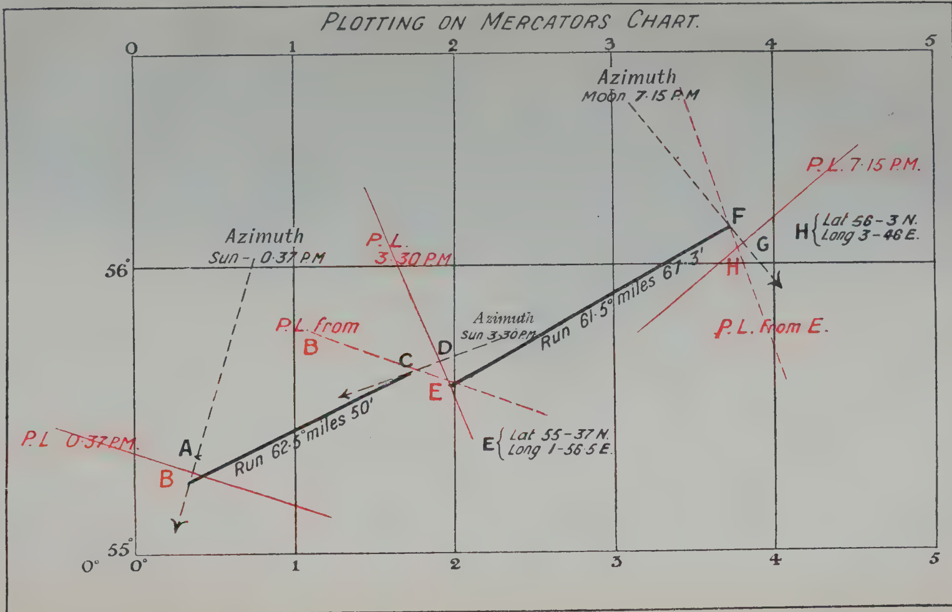
	h. m. s.				
W.H.A. or S.A.T.	21 42 54	Log. Hav.+	8·938636	Nat. Hav. ⊖	04835
Declination	S. 1 8 42	„ Cos. +	9·999913	„ „ L±D.	22984
Latitude	N. 56 9 0	„ Cos. +	9·745871		
				„ „ Z.D.±	27819
Lat.±Decln.	57 17 42	Log. Hav. ⊖ (Sum) +	8·684420	Calc. Z.D.+	
				Mer. Z.D.−	63 39 38

Lat.+Decln. if of different names. Lat.∼Decln. if of same name.

If the Obs. Z.D. is < Calc. Z.D. the "Position Point" is towards or nearer to the Heavenly Body = 5·75′.
If the Obs. Z.D. is > Calc. Z.D. the "Position Point" is away or further from the Heavenly Body.

Position by Plotting: Lat. 56° 3′ N. Long. 3° 46′ E.

Diagram 17.—Illustrating plotting of the results of Examples I., II., and III.



[To face p. 138.

Example 4.—Planet Observation for a 1st Position Line.

This example illustrates the manner in which a Planet's Hour Angle is obtained and a 1st Position Line is found as in Example 1.

The plotting of this observation is shown on diagram 18, where A is the Assumed Latitude and Longitude, the direction BA being Jupiter's Azimuth. The distance BA is the difference between the observed and calculated Zenith Distances.

The red line through B is the 1st Position Line.

Example 5.—Star Observation for a 2nd Position Line.

This observation illustrates the manner in which a Star's Hour Angle is obtained.

The angle between the Line of Bearing of Jupiter in the previous example and Denebola in this example is 99°.

The plotting is shown in diagram 18.

The 1st P.L. through B is moved parallel to itself the Run BC.

C is the Assumed Latitude and Longitude. The direction CD is the Azimuth of Denebola. The distance CD is the difference between the observed and calculated Zenith Distances.

E, where the 1st P.L. through C and the 2nd P.L. through D intersect, is the position of the ship at the time of the observation of Denebola.

Diagram 18 illustrates the method of plotting on squared or any other paper to a given scale of miles to inches.

In this diagram the scale is 60 miles = 3·6 inches.

A point A is taken as the assumed Lat. and Long. and an E. and W. line AL ruled through A.

From A is laid off AB—*i.e.* the Azimuth and difference of Jupiter's Z.D.'s, Example 4.

From B is laid off BC, the Run between observations of Jupiter and Denebola.

From C is laid off CD—*i.e.* the Azimuth and difference of Denebola's Z.D.'s, Example 5.

The 1st P.L. through C and the 2nd P.L. through D give at intersection E the position of the ship.

Through E rule MEL perpendicular to AL.

From AL lay off angle ALM equal to the Middle Latitude between A and E.

Then LE is the Diff. Lat. between the assumed position A and the true position E.

And ML is the Diff. Long. between the assumed position A and the true position E.

Thus the Latitude and Longitude of E are determined.

Ex. 4. D.R. or Working Position.

H.M.S. Lat. 56° 9′ N. Long. 4° 54′ E. Date, 9th May 1911, P.M.

Body observed—Jupiter.

Greenwich Date.	Day	h.	m.	*Watch Times.* h. m. s.	*Altitudes.* ° ′ ″
S.M.T.	May 9	9	0 P.M.		
Long. W.+ E.−			19·6 E.		
Gr. Date	May 9	8	40·4		

Planet's Semi-Diam.	′ ″	*Planet's Hor. Parallax.*	′ ″
S.D.	0 20	H.P.	0 2
Augn.		Redn.	
S.D.		H.P. in L.	
		P. in A.	

Correcting Data.

R.A.M.S. or Equation of Time.

	h.	m.	s.
	3	4	43·63
Corrn.	0	1	24·6
	3	6	8·23

Right Ascension.

	h.	m.	s.
	14	26	48·3
Corrn.	0	0	10·5
	14	26	37·8

Declination.

	°	′	″
	S. 13	4	50
Corrn.	0	0	49
	13	5	39

Westerly Hour Angle.

	h.	m.	s.
Watch Time	8	37	0
Error Fast − Slow +	0	3	39 S.
G.M.T.	8	40	39
Long. W.− E.+		19	36 E.
S.M.T.	9	0	15
Eq. of T. or R.A.M.S.+	3	6	8·3
S.A.T. or S.S.T.	12	6	23·23
R.A.−	14	26	37·8
W.H.A.	21	39	45·43

True Bearing from Azimuth Tables.

144° 30′.

Run 67° True. 51·3 miles.

Altitude.

	°	′	″
Obs. Alt. & I.E.	14	48	0
Corrns. in Alt.	0	8	35
	14	39	25
(Semi-Diam. UL− LL+)	0	0	20
	14	39	45
Parallax in Alt.			
True Alt.			
Reductn. to Meridian (For Ex Mer. Alts. only.)			
Mer. Alt.			
Z.D.	75	20	15
Decln. (+ same) (− diff.)			
Latitude			

Calculating.

	h.	m.	s.
W.H.A. or S.A.T.	21	39	45
Declination	S. 13	5	39
Latitude	N. 56	9	0
Lat.±Decln.	69	14	39

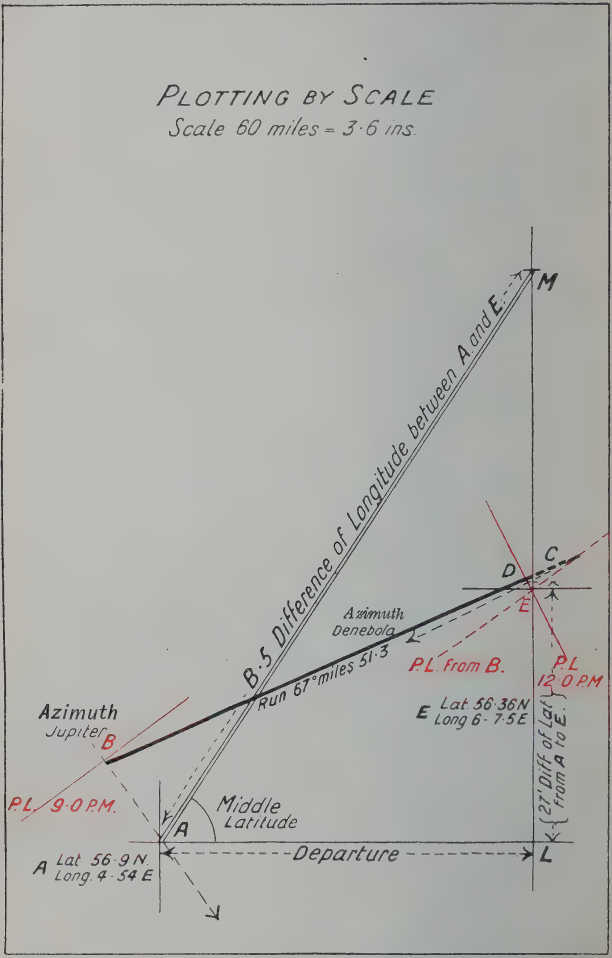
Log. Hav. +	8·957755
,, Cos. +	9·988560
,, Cos. +	9·745871
Log. Hav. ⊖ (Sum) +	8·692186

Nat. Hav. ⊖	049225
,, ,, L.±D.	322807
,, ,, Z.D.±	372032
Calc. Z.D.+	
Mer. Z.D.−	75 10 15

Lat.+Decln. if of different names.
Lat.∼Decln. if of same name.

If the Obs. Z.D. is < Calc. Z.D. the "Position Point" is towards or nearer to the Heavenly Body.
If the Obs. Z.D. is > Calc. Z.D. the "Position Point" is away or further from the Heavenly Body = 10′.

Diagram 18.—Illustrating plotting the results of Examples IV. and V.



Ex. 5. D.R. OR WORKING POSITION.

H.M.S. Lat. 56° 38′ N. Long. 6° 14′ E. Date, 9th May 1911, P.M.

Body observed—β Leonis Denebola.

Greenwich Data.				*Watch Times.*	*Altitude.*	*Moon's Semi-Diam.*		*Moon's Hor. Parallax.*	
	Day	h.	m.	h. m. s.	° ′ ″		′ ″		′ ″
S.M.T.	May 9	12	0			S.D.		H.P.	
Long. W.+ E.−			24·9			Augn.		Redn.	
Gr. Date	May 9	11	35·1			S.D.		H.P. in L. P. in A.	

CORRECTING DATA.

R.A.M.S. or Equation of Time.	h. m. s.	*Westerly Hour Angle.*	h. m. s.	*Altitude.*	° ′ ″
	3 4 43·63	Watch Time	11 30 59	Obs. Alt. & I.E.	33 53 50
Corrn. . .	0 1 55·2	Error Fast− Slow+	0 3 40 S.	Corrns. in Alt. .	0 6 26
	3 6 38·83	G.M.T. . . .	11 34 39		
		Long. W.− E.+ .	24 56 E.	(Semi-Diam. UL− LL+)	
Right Ascension.		S.M.T. . . .	11 59 35		
	h. m. s.	Eq. of T. or R.A.M.S.+	3 6 38·83	Parallax in Alt.	
	11 44 32·52				
Corrn. . .		S.A.T. or S.S.T. .	15 6 13·83	True Alt. . .	33 47 24
		R.A.− . .	11 44 32·52	Reductn. to Meridian (For Ex Mer. Alts. only.)	
		W.H.A. .	3 21 41·31	Mer. Alt.	
Declination.		*True Bearing from Azimuth Tables.*		Z.D. . . .	56 13 36
	N. 15° 4′ 7·88″	243° 20′.		Decln. (+ same) (− diff.)	
Corrn. . .				Latitude . .	

CALCULATING.

	h. m. s.				
W.H.A. or S.A.T.	3 21 41	Log. Hav.+	9·258735	Nat. Hav. ⊖	096361
Declination	N. 15 4 8	,, Cos. +	9·984804	,, ,, L.±D.	125890
Latitude	N. 56 38 0	,, Cos. +	9·740359		
				,, ,, Z.D.±	222251
Lat.±Decln.	41 33 52	Log. Hav. ⊖ (Sum) +	8·983898	Calc. Z.D.+ Mer. Z.D.−	56 15 18

{ Lat.+Decln. if of different names. Lat.∼Decln. if of same name. }

If the Obs. Z.D. is < Calc. Z.D. the "Position Point" is towards or nearer to the Heavenly Body = 2·7

If the Obs. Z.D. is > Calc. Z.D. the "Position Point" is away or further from the Heavenly Body.

Position by Plotting: Lat. 56° 36′ N. Long. 6° 7·5′ E.

(11) Observations for Latitude only

The practical observations for Latitude only are :—

(*a*) Meridian Altitudes, *i.e.* the altitude of a body when on the meridian of the Zenith or Nadir.
(*b*) Altitudes of the Pole Star, applicable North of the Equator only.
(*c*) Ex Meridian Altitudes, *i.e.* the altitude of a body when near the meridian of the Zenith or Nadir.

(*a*) Meridian Altitudes

The Upper Meridian Passage (U. Mer. Pass.) of a heavenly body is the time of the transit of its centre over the meridian of the observer's Zenith.

The Lower Meridian Passage (L. Mer. Pass.) of a heavenly body is the time of the transit of its centre over the meridian of the observer's Nadir.

The Hour Angle at U. Mer. Pass. is 0 hours or 24 hours, and at L. Mer. Pass. is 12 hours.

When a heavenly body is at U. Mer. Pass. its Zenith Distance measures the observer's distance from the place on the same meridian where the body is overhead, and the body's Declination measures the distance of this latter place from the Equator.

Therefore, if the observer and heavenly body are on the same side of the Equator, *i.e.* Lat. and Decl. both N. or both S., Latitude = Zenith Dist. + Decl. And if the observer and heavenly body are on opposite sides of the Equator, *i.e.* Lat. and Decl. one N. and the other S., Latitude = Zenith Dist. − Decl.

For L. Mer. Pass. Lat. and Decl. must be both N. or both S.; then Latitude = Altitude + Polar Dist.

Before taking Mer. Alts. it is advisable to find the exact time of Transit, for—

(*a*) If the observer is moving in any other direction than E. or W., the maximum altitude is not always the meridian altitude. Appreciable errors arise if the ship is steaming N. or S., *i.e.* directly to or from the heavenly body, at high speed.
(*b*) Continuously observing until maximum altitude is obtained is tedious and a waste of time. The moment of maximum altitude may be easily missed.
(*c*) In the case of the Moon the change of Decl. is so rapid that the maximum altitude is not always the Mer. Alt. even when steaming directly E. or W.

To find Watch Time of Sun's U. Mer. Pass.

(1) In W. Long. take the S.A.T. of Mer. Pass. as 0 hours on the civil date; in E. Long. take the S.A.T. of Mer. Pass. as 24 hours one day earlier.
(2) Apply the Long. in Time to the S.A.T. and obtain G.A.T.
(3) Apply the Eq. of Time at this G.A.T. to the G.A.T. and obtain G.M.T.
(4) Apply the Error of Watch (− if slow, + if fast) and obtain Watch Time of Mer. Pass.

N.B.—The Error in using Eq. of T. for the G.A.T. instead of for the G.M.T. is inappreciable.

To find the Watch Time of Moon's U. Mer. Pass.

The G.M.T of Moon's U. and L. Mer. Pass. at Greenwich is given on page II of each month in the Nautical Almanac. The increase in 24 hours, in minutes, is given between the times tabulated.

It is evident that if the Moon preserved a constant R.A. from the Sun its Mer. Pass., at the Local M.T. of all places, would be the same as the Greenwich Time of Mer. Pass.

The Moon, however, moves anticlockwise from the Sun a maximum of 68 minutes (17°) and a minimum of 40 minutes (10°) in 24 hours; consequently at Mer. Pass.—

In E. Long. the difference in the R.A. of Sun and Moon is less than at subsequent Greenwich Mer. Pass.; therefore Local M.T. of Mer. Pass. is less than the subsequent Greenwich Time of Mer. Pass.

In W. Long. the difference in the R.A. of Sun and Moon is greater than at preceding Greenwich Mer. Pass.; therefore Local M.T. of Mer. Pass. is greater than preceding Greenwich Time of Mer. Pass.

Greenwich Time of Mer. Pass. must therefore be corrected for Long., to find the Local or S.M.T. of Mer. Pass. at any place East or West of Greenwich.

The difference in time of Mer. Pass. tabulated is for 24 hrs. or 360°; for any other Long. the correction is $\frac{\text{Diff. in 24 hrs.} \times \text{Long. of place}}{360^\circ}$ (+ if in W. Long., − if in E. Long.).

This correction is given in Inman's Tables headed "Corr. in finding Moon's Mer. Pass."

To find Rough Greenwich Time of Moon's Mer. Pass. at any Place

(1) Take Greenwich Time of Mer. Pass. on the day from the Nautical Almanac.

(2) In W. Long. use the "Diff." in Mer. Pass. at Greenwich between the day and the following day.
In E. Long. use the "Diff." in Mer. Pass. at Greenwich between the day and the preceding day.

(3) Add the Corr. for "Diff." from Inman's Tables to the Long. of the place expressed in time.

(4) The Sum in (3), in W. Long. add to, and in E. Long. subtract from, the Greenwich Time in (1).

This gives Greenwich Time of Local Transit of Moon for correcting Declination, etc.

To find the Exact Watch Time of Mer. Pass.

(1) Correct R.A.M.S. and Moon's R.A. for Greenwich Time of Local Transit above.

(2) Subtract R.A.M.S. from Moon's R.A., obtaining S.M.T. of Local Transit.

(3) Apply Long. in time to S.M.T. and obtain G.M.T.

(4) Apply Error of Watch (− if slow, + if fast) and obtain Watch Time of Mer. Pass.

In the worked example this working is shown in column headed "Westerly Hour Angle," working from bottom to top. In practice this exactitude is generally unnecessary.

Days on which no Transits occur

Owing to the rapid increase of Moon's R.A., over 24 hours elapses between transits.

If Moon's R.A. = R.A.M.S. there is no upper transit, and asterisks indicate this.

If Moon's R.A. differs by 12 hours from R.A.M.S. there is no lower transit, as is also shown by asterisks.

To find the Rough Time of a Planet's U. Mer. Pass.

The U. Mer. Pass.'s of Venus, Mars, Jupiter, Saturn at Greenwich are given on pages XI and XII of each month in the Nautical Almanac. If the G.M.T. of Mer. Pass. is not changing rapidly, this may be taken as the Local Mean Time of Mer. Pass. at any other place.

Then, to find the Greenwich Time of Local Transit at any place, apply to the Greenwich Time of Mer. Pass. the Long. of the place in time, adding if W., subtracting if E.

To find the Time of a Planet's Mer. Pass.

Strictly, a Planet's Mer. Pass. at any place should, as in the case of the Moon, be corrected for Long. This is generally unnecessary, but the method will be explained.

All planets, like the Moon, move anticlockwise round the Sun, but their R.A.'s may—

(*a*) Increase faster than the R.A.M.S., like the Moon, and Corr. for Long. is + for W. and − for E. Long.

(*b*) Increase slower than the R.A.M.S., unlike the Moon, and Corr. for Long. is − for W. and + for E. Long.

(*c*) Actually decrease, when, unlike the Moon, the Corr. for Long. is − for W. and + for E. Long.

The rules for finding Planet's Mer. Pass. are the same as those for the Moon, except:—

If the transits are getting later, add the Corr. for Long. to the Long. in Time.

If the transits are getting earlier, subtract the Corr. for Long. from the Long. in Time.

The Corr. for Long. = Diff. between successive transits $\times \frac{\text{Long.}}{360^\circ}$.

Days on which no Transit or Double Transits Occur

When a Planet's R.A. = R.A.M.S. there will be no transit or a double transit, thus:—

In case (*a*) above the interval between two successive transits is over 24 hours, and no transit will occur, as in the case of the Moon, and this is indicated by asterisks.

In cases (*b*) and (*c*) above the interval between two successive transits is under 24 hours, and two transits will occur on such a day, the time of each being printed in small figures.

The Exact Time of a Planet's Mer. Pass.

This is found in the same way as in the case of the Moon, and is illustrated in the worked example in the column W.H.A., working from bottom to top.

To find the Time of a Star's Mer. Pass.

(1) Star's R.A. − R.A.M.S. gives rough S.M.T. of Mer. Pass.

(2) Apply the Long. and obtain rough G.M.T. of Mer. Pass.

(3) Subtract from this G.M.T. the augmentation of R.A.M.S. at 10 seconds per hour of G.M.T.

(4) Apply the error of the watch (− if slow, + if fast) and obtain accurate watch time of Mer. Pass.

To find what Stars transit at a given S.M.T.

Add the S.M.T. to the R.A.M.S. This gives the R.A. of stars on transit at that time.

Double Transits

As a Sidereal Day is shorter than a M.S. Day, double transits occur, as in the case of Planets, when the Star's R.A. = R.A.M.S. Both transits are then tabulated.

Ex. 6. D.R. or Working Position.

H.M.S. Lat. 55° 10′ N. Long. 0° 6′ E. Date, 9th May 1911, A.M.

Body observed—Sun Meridian Altitude.

Greenwich Date.		*Watch Times*	*Altitudes.*	*Moon's Semi-Diam.*	*Moon's Hor. Parallax.*
	Day h. m.	h. m. s.	° ′ ″	′ ″	′ ″
S.M.T.	May 9 11 56 A.M.	23 52 22	51 48 30	S.D.	H.P.
Long. W. + E. −	0·1 E.		I.E. 0 10	Augn.	Redn.
Gr. Date	May 8 23 55·9		51 48 20	S.D.	H.P. in L. P. in A.

Correcting Data.

R.A.M.S. or Equation of Time.		*Westerly Hour Angle.*		*Altitude.*	
	h. m. s.		h. m. s.		° ′ ″
	0 3 37·91	Watch Time	23 52 22	Obs. Alt. & I.E.	51 48 20
Corrn. . .	0 0 0·01	Error Fast − Slow +	0 3 36 S.	Corrns. in. Alt. .	0 10 13
	0 3 37·9	G.M.T. . . .	23 55 58		51 58 33
		Long. W. − E. +	24 E.	(Semi-Diam. UL− LL+)	
Right Ascension.		S.M.T. . . .	23 56 22		
	h. m. s.	Eq. of T. or R.A.M.S. +	0 3 38	Parallax in Alt.	
Corrn. . .		S.A.T. or 8th S.S.T. .	24 0 0	True Alt. . .	
		R.A. − . .		Reductn. to Meridian (For Ex Mer. Alts. only.)	
		W.H.A. .		Mer. Alt.	
Declination.		*True Bearing from Azimuth Tables.*		Z.D.	38 1 27
	° ′ ″				
	N. 17 7 48·7				
Corrn. . .	0 0 0·3			Decln. (+same) (−diff.)	N. 17 7 48
	17 7 48·4			Latitude .	N. 55 9 15

Ex. 7. D.R. OR WORKING POSITION.

H.M.S. Lat. 56° 16′ N. Long. 5° 0′ E. Date, 9th May 1911, P.M.

Body observed—Moon Meridian Altitude, UL.

Greenwich Date.	*Watch Times.*	*Altitudes.*	*Moon's Semi-Diam.*	*Moon's Hor. Parallax.*
Day h. m.	h. m. s.	° ′ ″	′ ″	′ ″
S.M.T. May 9 9 36·5	9 12 17	31 33 40	S.D. 15 8	H.P. 55 30
Long W.+ E.− 20·6 E.		I.E. 0 10−	Augn. 0 7·6	Redn. 0 7
Gr. Date May 9 9 15·9		31 33 30	S.D. 15 15·6	H.P. in L. 55 23
				P. in A. 45 48

Diff. of Mer. Pass. = 41·5 mins. Corr. = ·6 min. Long. = 20 mins.

CORRECTING DATA.

R.A.M.S. or Equation of Time.	*Westerly Hour Angle.*	*Altitude.*
h. m. s.	h. m. s.	° ′ ″
3 4 43·63	Watch Time 9 12 17	Obs. Alt. & I.E. 31 33 30
Corrn. . . 0 1 31·11	Error Fast − Slow + 0 3 40 S.	Corrns. in Alt. . 0 5 1
3 6 14·74	G.M.T. . . 9 15 57	31 28 29
	Long W.− E.+ 20 0 E.	(Semi-Diam. UL− LL+) 0 15 16
Right Ascension.	S.M.T. . . 9 35 57	31 13 13
h. m. s.	Eq. of T. or R.A.M.S.+ 3 6 14·7	Parallax in Alt. 0 45 48
12 41 42·61	S.A.T. or S.S.T. . 12 42 11·7	True Alt. . . 31 59 1
Corrn. . . 0 0 29·3	R.A.− . . 12 42 11·9	Reductn. to Meridian (For Ex Mer. Alts. only.)
12 42 11·9	W.H.A. . . 0 0 0	
Declination.	*True Bearing from Azimuth Tables.*	Mer. Alt.
° ′ ″		Z.D. . . . 58 0 59
S. 1 37 37·3		Decln. (+ same) (− diff.) S. 1 41 27
Corrn. . . 0 3 50		
1 41 27·3		Latitude . . N. 56 19 32

Ex. 8. D.R. OR WORKING POSITION.

H.M.S. Lat. 56° 30′ N. Long. 6° 0′ E. Date, 9th May 1911, P.M.

Body observed—Jupiter Meridian Altitude.

Greenwich Date.	*Watch Times.*	*Altitudes.*	*Moon's Semi-Diam.*	*Moon's Hor. Parallax.*
S.M.T., Day h. m.	h. m. s.	° ′ ″		
Mer Pass. May 9 11 20·1	10 52 34	21 32 10	S.D. 0 20	H.P. 0 2
Long. W.+ E.− 24 E.		1 E. 0 10−	Augn.	Redn.
Gr. Date May 9 10 56		21 32 0	S.D.	H.P. in L. P. in A.

Diff. of Mer. Pass., 4·4 mins. Decreasing corrn.=·074.

CORRECTING DATA.

R.A.M.S. or Equation of Time.	*Westerly Hour Angle.*	*Altitude.*
h. m. s.	h. m. s.	° ′ ″
3 4 43·63	Watch Time 10 52 24	Obs. Alt. & I.E. 20 32 0
Corrn. 0 1 47·8	Error Fast − Slow + 3 39 S.	Corrns. in Alt. 0 7 29
3 6 31·43	G.M.T. 10 56 3	20 24 31
	Long. W. − E. + 24 0 E.	(Semi-Diam. UL− LL+) 0 0 20
Right Ascension.	S.M.T. 11 20 3	20 24 51
h. m. s.	Eq. of T. or R.A.M.S.+ 3 6 31	Parallax in Alt.
14 26 34·5	S.A.T. or S.S.T. 14 26 34	True Alt.
Corrn. 0 0 0·5	R.A.− 14 26 34	Reductn. to Meridian (For Ex Mer. Alts. only.)
14 26 34	W.H.A. 0 0 0	Mer. Alt.
Declination.	*True Bearing from Azimuth Tables.*	Z.D. 69 35 9
° ′ ″ S. 13 3 45		Decln. (+ same) (− diff.) S. 13 3 45
Corrn. 0 0 2·3		
13 3 47·3		Latitude N 56 31 24

Ex. 9. D.R. or Working Position.

H.M.S. Lat. 56° 35′ N. Long. 5° 45′ E. Date, 9th May 1911.

Body observed—Arcturus Meridian Altitude.

Greenwich Date.		*Watch Times.*	*Altitudes.*	*Moon's Semi-Diam.*	*Moon's Hor. Parallax.*
	Day h. m.	h. m. s.	° ′ ″	′ ″	′ ″
S.M.T.	May 9 11 4 P.M.	10 38 29	53 15 0	S.D.	H.P.
Long. W.+ E.−	23 E.		I E. 0 10−	Augn.	Redn.
					H.P. in L.
Gr. Date	May 9 10 41		53 14 50	S.D.	P. in A.

Correcting Data.

R.A.M.S. or Equation of Time.	
	h. m. s.
	3 4 43·63
Corrn. . .	0 1 45·5
	3 6 29·1

Right Ascension.	
	h. m. s.
	14 11 37·86
Corrn. . .	

Declination.	
	° ′ ″
	N. 19 38 34
Corrn. . .	

Westerly Hour Angle.	
	h. m. s.
Watch Time	10 38 29
Error Fast − Slow +	0 3 40 S.
G.M.T. . .	10 42 9
Long. W.− E.+	23 0 E.
S.M.T. . .	11 5 9
Eq. of T. or R.A.M.S.+	3 6 29
S.A.T. or S.S.T. .	14 11 38
R.A.− . .	14 11 38
W.H.A. .	0 0 0

True Bearing from Azimuth Tables.

Altitude.	
	° ′ ″
Obs. Alt. & I.E.	53 14 50
Corrns. in Alt. .	0 5 45
	53 9 5
(Semi-Diam. UL− LL+)	
Parallax in Alt.	
True Alt. . .	
Reductn. to Meridian } For Ex Mer. Alts. only.	
Mer. Alt.	
Z.D. . . .	36 50 55
Decln. (+same) (−diff.)	N. 19 38 34
Latitude .	N. 56 29 29

(*b*) **The Pole Star**

α Ursæ Minoris, the Pole Star, moves round the N. Celestial Pole in a circle of about 35′ radius. The Pole Star, N. Celestial Pole, and ζ Ursæ Majoris are in a straight line.

ζ Ursæ Majoris is the middle star in the tail of the Great Bear, Ursæ Majoris.

When this line is horizontal, the altitudes of the Pole Star and ζ Ursæ Majoris are equal, and these altitudes corrected for Dip and Refraction give the Latitude of the observer.

When this line is vertical, and the Pole Star is above ζ Ursæ Majoris, the altitude of the Pole Star, corrected for Dip and Refraction, is about 35′ more than the Latitude; and when the Pole Star is below ζ Ursæ Majoris, the corrected altitude of the Pole Star is about 35′ less than the Latitude.

Pole Star Altitudes corrected for Dip and Refraction, and by the tables pages 155 to 159 inclusive, Nautical Almanac, give the True Altitude of the Pole or the Latitude of the observer.

The procedure is as follows :—Finding the Ship Sidereal Time—

(1) Observe the altitude of the Pole Star and note the time.
(2) Obtain a rough Greenwich Date and the Ship Mean Time.
(3) Augment the R.A.M.S. for Greenwich Time at 10 seconds per hour.
(4) Find the S.S.T., *i.e.* S.M.T. + R.A.M.S.

In the worked example this is shown in column W.H.A., working down to S.S.T.

Correcting the altitude—

(1) Correct the observed altitude for Index Error, Dip and Refraction.
(2) Subtract 1′ in order that the correction Table II. may be additive.
(3) Apply the corrections Tables I., II., and III., Nautical Almanac, pages 155 to 159.

Table I.—Enter with the S.S.T. or Local Sidereal Time. The correction is given for every 2 minutes, and is + or − as marked.

Table II.—Enter with the S.S.T. and Altitude. This correction is added.

Table III.—Enter with the S.S.T. and Date. This correction is added.

The result gives the Altitude of the observer, for

Altitude of Pole = Latitude of Place.

Ex. 10. D.R. OR WORKING POSITION.

H.M.S. Lat. 56° 55′ N. Long. 7° 50′ E. Date, 10th May 1911.

Body observed—Pole Star.

Greenwich Date.	*Watch Times.*	*Altitudes.*	*Moon's Semi-Diam.*	*Moon's Hor. Parallax.*
Day h. m.	h. m. s.	° ′ ″	′ ″	′ ″
S.M.T. May 10 3 15 A.M.	14 41 36	56 45 40	S.D.	H.P.
Long. W.+ E.− 31·3		I.E. 0 10−	Augn.	Redn.
Gr. Date May 9 14 43·7		56 45 30	S.D.	H.P. in L. P. in A.

CORRECTING DATA.

R.A.M.S. or Equation of Time.	*Westerly Hour Angle.*	*Altitude.*
h. m. s.	h. m. s.	° ′ ″
3 4 43·63	Watch Time 14 41 36	Obs. Alt. & I.E. 56 45 40
Corrn. . . 0 2 25·5	Error Fast − Slow + 0 3 41 S.	Corrns. in Alt. 0 5 39
3 7 9·13	G.M.T. . . 14 45 17	56 40 1
	Long. W. − E. + 31 20 E.	(Semi-Diam. UL− LL+) Constant . 0 1 0
Right Ascension.	S.M.T. . . 15 16 37	56 39 1
h. m. s.	Eq. of T. or R.A.M.S. + 3 7 9	Parallax in Alt. 1st Corrn. + or − 19 4+
Corrn. . .	S.A.T. or S.S.T. . 18 23 46	True Alt. . . 56 58 5
	R.A.− . .	Re-ductn. to Meri-dian (For Ex Mer. Alts. only.) 2nd cor. + 0 1 1
	W.H.A. .	3rd Cor. + 0 0 51
Declination.	*True Bearing from Azimuth Tables.*	Mer. Alt. 56 59 57
° ′ ″		Z.D. . . .
Corrn. . .		Decln. (+ same) (− diff.)
		Latitude N. 56 59 57

(c) Ex Meridian Altitudes

The Ex Meridian Altitude of a heavenly body is its altitude when near the meridian of the observer or when near the meridian passing through the Nadir of the observer.

In the former case, when near the meridian of the Zenith, it is called Ex Meridian above Pole.

In the latter case, when near the meridian of the Nadir, it is called Ex Meridian below Pole.

The observed altitude is corrected as customary, and "augmented" if above the Pole or "reduced" if below the Pole to what the altitude would have been if the observer had measured the body's altitude when in transit on the meridian of the Zenith or Nadir.

This "augmented" altitude if above the Pole subtracted from 90° gives the Meridian Zenith Distance.

The sum or difference of this Mer. Zen. Dist. and the Decln. (sum if both N. or both S., difference if one N. and the other S.) gives the Latitude.

The "reduced" altitude if below the Pole added to the Polar Distance gives the Latitude.

The methods of correcting Ex Mer. Alts. to obtain the Mer. Alt. are by—

(1) Hall's Ex Meridian Altitude Tables (as explained on the Tables, pages 157 and 158, also page 159).
(2) Brent and Williams's Ex Meridian Tables (*v.* Example 11 of Sun Ex Mer. Alt.).
(3) Hall's Nautical Slide Rule (this performs the calculation by inspection).
(4) By calculation (*v.* Example 12 of Moon Ex. Mer. Alt.).

Correcting by calculation is conveniently done on the forms for Position Line sights, except—

(1) The Natural Haversine of z (the observed Zen. Dist.) is used in place of Natural Haversine $(L \pm D)$.
(2) In Ex Mer. Alts. above Pole take the difference of Hav. z and Hav. θ instead of the sum.
In Ex. Mer. Alts below Pole take the sum of Hav. z and Hav. θ instead of the difference.

The proof of these differences is as follows :—
From the formula on page 124 was proved

$$\text{Hav. } z = \text{Hav. } (L \sim D) + \text{Hav. } \theta,$$

where z is the Ex Meridian Zenith Distance.

Now Z, the required Meridian Zenith Distance $= L \sim D$, where L is the True Latitude and not the assumed Latitude used in calculating θ.

Therefore Hav. z = Hav. Z + Hav. θ, or Hav. Z = Hav. z − Hav. θ above the Pole,

and Hav. z = Hav. Z − Hav. θ, or Hav. Z = Hav. z + Hav. θ below the Pole,

for below the Pole the Hour Angle of an Ex Meridian Altitude is nearly 12 hours, and being over 90° this changes the sign of Hav. θ from + to −.

Notes on Ex Meridian Altitudes

(1) An assumed Latitude is required for finding θ. An error in this assumed Latitude does not appreciably affect the result; since the Hour Angle (p) is small θ is small and changes very slowly.

(2) There are two Zenith Distances, the Ex Meridian Zenith Distance (z) and the Meridian Zenith Dist. (Z), which latter is the Zenith Distance of the body when it was on the meridian of the observer.

(3) The Latitude obtained is the Latitude of the observer at the time of observation and not at noon.

(4) The Position Line of the observer is at right angles to the Azimuth of the body at the time of observation. It is not E. and W. as in Meridian Altitudes. The Position Line should be drawn through the point fixed by the True Latitude, and, the assumed Longitude used for the Greenwich Date.

(5) If this Position Line is used in conjunction with a subsequent observation, it must be moved parallel to itself the direction and distance of the Run between the two observations, and not, the Run from noon.

(6) An Ex Mer. Alt. should not be observed more than 1 hour from time of Transit.

(7) An Ex Mer. Alt. worked by Marc St Hilaire's method is more correct for fixing in conjunction with a subsequent sight, though the difference is immaterial.

Correcting Data

The S.A.T., W.H.A., and G.M.T. are found as in Position Line observations, the time of the observation being accurately taken.

The R.A.M.S., R.A., Equation of Time, and Declination are taken from the Nautical Almanac and corrected for G.M.T. as already explained for Position Line observations.

The worked example of a Sun Ex Meridian Altitude is the same observation as the first worked Position Line sight.

Ex. 11. D.R. or Working Position.

H.M.S. Lat. 55° 20′ N. Long. 0° 25′ E. Date, 9th May 1911.

Body observed—Sun (Ex Meridian Altitude, LL).

Greenwich Date.			*Watch Times.*	*Altitudes.*	*Moon's Semi-Diam.*		*Moon's Hor. Parallax.*	
	Day	h. m.	h. m. s.	° ′ ″		′ ″		′ ″
S.M.T.	May 9	0 37·5 P.M.			S.D.		H.P.	
Long. W.+ E. −		1·7 E.			Augn.		Redn.	
Gr. Date	May 9	0 35·8			S.D.		H.P. in L. P. in A.	

Correcting Data.

R.A.M.S. or Equation of Time.		*Westerly Hour Angle.*		*Altitude.*	
	h. m. s.		h. m. s.		° ′ ″
	0 3 37·92	Watch Time	0 32 26	Obs. Alt. & I.E.	50 53 50
Corrn. . .	0 0 0·08	Error Fast − Slow +	0 3 36 S.	Corrns. in Alt. .	0 11 33
	0 3 38	G.M.T. .	0 36 2		51 5 23
		Long. W. − E. +	1 40 E.	(Semi-Diam. UL− LL+)	
Right Ascension.		S.M.T. .	0 37 42		
	h. m. s.	Eq. of T. or R.A.M.S.+	0 3 38	Parallax in Alt.	
Corrn. . .		S.A.T. or S.S.T. .	0 41 20	True Alt. . .	51 5 23
		R.A.− . .		Reductn. to Meridian (For Ex Mer. Alts. only.)	0 28 29
					0 19 50
		W.H.A. .			0 0 34
Mean Noon Declination.				Mer. Alt.	51 54 16
	° ′ ″	*True Bearing from Azimuth Tables.*		Z.D. . . .	38 5 45
	N. 17 7 51·1			Decln. (+ same) (− diff.)	17 8 15
Corrn. . .	0 0 24·3				
	17 8 15			Latitude . .	55 14 0

Calculating.

	h. m. s.				
W.H.A. or S.A.T.		Log. Hav.+		Nat. Hav. ⊖	
Declination .		,, Cos. +		,, ,, L.±D.	
Latitude . .		,, Cos. +		,, ,, Z.D.±	
Lat.±Decln. .		Log. Hav. ⊖ (Sum) +		Calc. Z.D.+ Mer. Z.D.−	

Ex. 12. D.R. or Working Position.

H.M.S. Lat. 56° 10′ N. Long. 4° 48′ E. Date, 9th May 1911.

Body observed—Moon (Ex Meridian Altitude, UL).

Greenwich Date.		*Watch Times.*	*Altitudes.*	*Moon's Semi-Diam.*	*Moon's Hor. Parallax.*
	Day h. m.	h. m. s.	° ′ ″	′ ″	′ ″
S.M.T.	May 9 9 12 P.M.	8 51 25	31 31 40	S.D. 15 8	H.P. 55 30
Long. W.+ E.−	19·2 E.		I.E. 0 10−	Augn. 0 7·6	Redn. 0 7
Gr. Date	May 9 8 52·8		31 31 30	S.D. 15 15·6	H.P. in L. 55 23
					P. in A. 45 48

Correcting Data.

R.A.M.S. or Equation of Time.	h. m. s.
	3 4 43·63
Corrn. . .	0 1 28
	3 6 11·63

Right Ascension.	h. m. s.
	12 41 42·61
Corrn. . .	0 0 9·3
	12 41 33·3

Declination.	° ′ ″
	S. 1 37 37·3
Corrn. . .	0 1 13
	1 36 24

Westerly Hour Angle.	h. m. s.
Watch Time	8 51 25
Error Fast − Slow +	0 3 40 S.
G.M.T. . .	8 55 5
Long. W.− E.+	19 12 E.
S.M.T. . .	9 14 17
Eq. of T. or R.A.M.S.+	3 6 11·6
S.A.T. or S.S.T. . .	12 20 28·6
R.A.− . .	12 41 33·3
W.H.A. .	23 38 55·3

True Bearing from Azimuth Tables.

Altitude.	° ′ ″
Obs. Alt. & I.E.	31 31 30
Corrns. in. Alt. .	0 5 1
	31 26 29
(Semi-Diam. UL− LL+)	0 15 15
	31 11 14
Parallax in Alt.	0 45 48
True Alt. . .	31 57 2
Reductn. to Meridian (For Ex Mer. Alts. only.)	(Z)58 2 58
Mer. Alt	
Z.D. . . .	57 53 29
Decln. (+ same) (− diff.)	S. 1 36 24
Latitude .	N. 56 17 5

Calculating.

	h. m. s.				
W.H.A. or S.A.T.	23 38 55	Log. Hav. +	7·325284	Nat. Hav. ⊖	0001150−
Declination	S. 1 36 24	,, Cos. +	9·999830	(Z) ,, ,, L.±D.	0235406+
Latitude .	N. 56 10 0	,, Cos. +	9·745683	,, ,, Z.D.±	0234256
Lat. ∼ Decln.	. Not used.	Log. Hav. ⊖ (Sum) +	7·070797	Calc. Z.D.+ Mer. Z.D.−	57 53 29

Ex-Meridian Altitude Tables.

By the Rev. William Hall, B.A., R.N.

Table I.—Values of $N = \frac{2 \sin^2 15'}{\sin 1'} h^2$.

Hour Angle.		N	Hour Angle.		D	P	N	Hour Angle.		D	P	N	Hour Angle.		D	P	N	Hour Angle.		D	P	N
m.	s.		m.	s.				m.	s.				m.	s.				m.	s.			
0	00	**0**	12	22			**50**	30	17			**300**	41	00			**550**	49	27			**800**
1	45	1	12	58	7	1	55	30	32	3	1	305	41	11	2	1	555	49	36	2	1	805
2	28	2	13	32	14	2	60	30	47	6	2	310	41	22	4	2	560	49	45	4	2	810
3	02	3	14	06	21	3	65	31	02	9	3	315	41	33	7	3	565	49	54	5	3	815
3	30	4	14	37	28	4	70	31	16	12	4	320	41	44	9	4	570	50	04	7	4	820
3	55	5	15	08			75	31	31			325	41	55			575	50	13			825
4	17	6	15	38	6	1	80	31	46	3	1	330	42	06	2	1	580	50	22	2	1	830
4	37	7	16	07	11	2	85	32	00	6	2	335	42	17	4	2	585	50	31	4	2	835
4	57	8	16	35	17	3	90	32	14	8	3	340	42	28	7	3	590	50	40	5	3	840
5	14	9	17	02	23	4	95	32	28	11	4	345	42	38	9	4	595	50	49	7	4	845
5	32	**10**	17	29			**100**	32	42			**350**	42	48			**600**	50	58			**850**
5	48	1	17	55	5	1	105	32	56	3	1	355	43	00	2	1	605	51	07	2	1	855
6	04	2	18	20	10	2	110	33	10	6	2	360	43	10	4	2	610	51	16	4	2	860
6	18	3	18	45	15	3	115	33	24	8	3	365	43	21	6	3	615	51	25	5	3	865
6	32	4	19	09	20	4	120	33	38	11	4	370	43	32	8	4	620	51	33	7	4	870
6	46	5	19	33			125	33	51			375	43	42			625	51	42			875
7	00	6	19	56	4	1	130	34	04	3	1	380	43	52	2	1	630	51	51	2	1	880
7	13	7	20	19	9	2	135	34	18	5	2	385	44	03	4	2	635	52	00	3	2	885
7	25	8	20	41	14	3	140	34	31	8	3	390	44	13	6	3	640	52	09	5	3	890
7	37	9	21	03	18	4	145	34	44	10	4	395	44	24	8	4	645	52	18	6	4	895

7	49	**20**	21	25			**150**	34	58			**400**	44	35			**650**	52	26			**900**
8	01	1	21	46	4	1	155	35	11	3	1	405	44	45	2	1	655	52	35	2	1	905
8	12	2	22	07	8	2	160	35	24	5	2	410	44	55	4	2	660	52	43	3	2	910
8	23	3	22	27	12	3	165	35	37	8	3	415	45	05	6	3	665	52	52	5	3	915
8	34	4	22	47	16	4	170	35	49	10	4	420	45	15	8	4	670	53	01	6	4	920
8	44	5	23	07			175	36	02			425	45	25			675	53	10			925
8	55	6	23	27	4	1	180	36	15	3	1	430	45	35	2	1	680	53	18	2	1	930
9	05	7	23	46	8	2	185	36	28	5	2	435	45	45	4	2	685	53	27	3	2	935
9	15	8	24	06	12	3	190	36	40	8	3	440	45	55	6	3	690	53	35	5	3	940
9	25	9	24	25	15	4	195	36	53	10	4	445	46	05	8	4	695	53	44	6	4	945
9	34	**30**	24	44			**200**	37	05			**450**	46	15			**700**	53	52			**950**
9	44	1	25	02	4	1	205	37	17	2	1	455	46	25	2	1	705	54	01	2	1	955
9	53	2	25	20	7	2	210	37	29	5	2	460	46	35	4	2	710	54	10	3	2	960
10	02	3	25	38	11	3	215	37	42	7	3	465	46	45	6	3	715	54	18	5	3	965
10	11	4	25	56	14	4	220	37	54	10	4	470	46	55	8	4	720	54	27	6	4	970
10	20	5	26	13			225	38	06			475	47	05			725	54	35			975
10	29	6	26	31	3	1	230	38	18	2	1	480	47	14	2	1	730	54	43	2	1	980
10	38	7	26	48	7	2	235	38	30	5	2	485	47	24	4	2	735	54	52	3	2	985
10	47	8	27	05	10	3	240	38	42	7	3	490	47	33	5	3	740	55	00	5	3	990
10	55	9	27	22	14	4	245	38	53	10	4	495	47	43	7	4	745	55	08	6	4	995
11	04	**40**	27	38			**250**	39	05			**500**	47	52			**850**	55	17			**1000**
11	12	1	27	55	3	1	255	39	17	2	1	505	48	02	2	1	755	55	25	2	1	1005
11	20	2	28	11	6	2	260	39	29	5	2	510	48	11	4	2	760	55	34	3	2	1010
11	28	3	28	28	10	3	265	39	40	7	3	515	48	21	5	3	765	55	42	5	3	1015
11	36	4	28	44	13	4	270	39	52	9	4	520	48	31	7	4	770	55	50	6	4	1020
11	44	5	29	00			275	40	03			525	48	40			775	55	59			1025
11	52	6	29	15	3	1	280	40	14	2	1	530	48	49	2	1	780	56	07	2	1	1030
11	59	7	29	31	6	2	285	40	26	4	2	535	48	58	4	2	785	56	15	3	2	1035
12	07	8	29	46	9	3	290	40	37	7	3	540	49	08	5	3	790	56	23	5	3	1040
12	14	9	30	01	12	4	295	40	49	9	4	545	49	17	7	4	795	56	31	6	4	1045
12	22	**50**	30	17			**300**	41	00			**550**	49	27			**800**	56	37			**1050**

Explanation of Table.—To find Number (N) for Hour Angle [*e.g.* $38^{m\cdot}\ 23^{s\cdot}$] take N for Hour Angle next below [$38^{m\cdot}\ 18^{s\cdot}$], to which add proportional part (P) for the difference (D) between these two Hour Angles [$38^{m\cdot}\ 18^{s\cdot}$ and $38^{m\cdot}\ 23^{s\cdot}$]. The number required in example is therefore 480+2=482.

TABLE II.—NATURAL TANGENTS. (T.)

Lat. or Dec.	D	T	Lat. or Dec.	D	T	Lat. or Dec.	D	T	Lat. or Dec.	D	T
° ′			° ′			° ′			° ′		
0 00		**0**	26 34		**50**	45 00		**100**	56 19		**150**
0 34	3	1	27 01	3	1	45 17	2	1	56 29	1	1
1 09	7	2	27 28	5	2	45 34	3	2	56 40	2	2
1 43	10	3	27 55	8	3	45 51	5	3	56 50	3	3
2 18	14	4	28 22	11	4	46 07	7	4	57 00	4	4
2 52	17	5	28 49	13	5	46 24	8	5	57 10	5	5
3 26	21	6	29 15	16	6	46 40	10	6	57 20	6	6
4 00	24	7	29 41	19	7	46 56	12	7	57 30	7	7
4 34	28	8	30 07	21	8	47 12	13	8	57 40	8	8
5 02	31	9	30 32	24	9	47 28	15	9	57 50	9	9
5 43		**10**	30 58		**60**	47 44		**110**	58 00		**160**
6 17	3	1	31 23	2	1	47 59	2	1	58 09	1	1
6 52	7	2	31 48	5	2	48 14	3	2	58 19	2	2
7 24	10	3	32 13	7	3	48 30	5	3	58 28	3	3
7 59	14	4	32 37	10	4	48 45	6	4	58 38	4	4
8 32	17	5	33 01	12	5	48 59	8	5	58 47	5	5
9 05	21	6	33 25	15	6	49 14	9	6	58 56	6	6
9 39	24	7	33 49	17	7	49 29	11	7	59 05	6	7
10 12	28	8	34 13	20	8	49 43	12	8	59 14	7	8
10 40	31	9	34 36	22	9	49 58	14	9	59 23	8	9
11 10		**20**	35 00		**70**	50 12		**120**	59 32		**170**
11 53	3	1	35 23	2	1	50 26	1	1	59 41	1	1
12 20	6	2	35 45	4	2	50 40	3	2	59 50	2	2
12 57	10	3	36 08	7	3	50 53	4	3	59 59	3	3
13 30	13	4	36 30	9	4	51 07	5	4	60 07	4	4
14 02	16	5	36 52	11	5	51 20	7	5	60 15	4	5
14 34	19	6	37 14	14	6	51 34	8	6	60 24	5	6
15 07	23	7	37 36	16	7	51 47	10	7	60 32	6	7
15 30	26	8	37 57	18	8	52 00	11	8	60 40	7	8
16 10	29	9	38 19	20	9	52 13	12	9	60 49	8	9
16 42		**30**	38 40		**80**	52 26		**130**	60 57		**180**
17 13	3	1	39 00	2	1	52 39	1	1	61 04	1	1
17 45	6	2	39 21	4	2	52 51	2	2	61 13	2	2
18 16	9	3	39 42	6	3	53 03	4	3	61 20	2	3
18 47	12	4	40 02	8	4	53 16	5	4	61 29	3	4
19 17	15	5	40 22	10	5	53 28	6	5	61 36	4	5
19 48	18	6	40 42	12	6	53 40	7	6	61 45	5	6
20 18	21	7	41 01	14	7	53 52	9	7	61 52	5	7
20 48	24	8	41 21	16	8	54 04	10	8	61 59	6	8
21 18	27	9	41 40	18	9	54 16	11	9	62 07	7	9
21 48		**40**	41 59		**90**	54 28		**140**	62 14		**190**
22 18	3	1	42 18	2	1	54 39	1	1	62 22	1	1
22 47	6	2	42 37	4	2	54 51	2	2	62 29	1	2
23 16	9	3	42 55	5	3	55 02	3	3	62 37	2	3
23 45	12	4	43 14	7	4	55 13	4	4	62 44	3	4
24 14	14	5	43 32	9	5	55 24	5	5	62 51	4	5
24 42	17	6	43 50	11	6	55 35	6	6	62 58	4	6
25 10	20	7	44 08	13	7	55 46	7	7	63 05	5	7
25 38	23	8	44 25	14	8	55 57	8	8	63 12	6	8
26 06	26	9	44 43	16	9	56 08	9	9	63 19	6	9
26 34		**50**	45 00		**100**	56 19		**150**	63 26		**200**

Explanation of Table.—To take out Tangent of Lat. or Dec. [*e.g.* 42° 48′] take T for the quantity next below [42° 37′], to which add for proportional part, and as a decimal, the figure in column T opposite the difference (D) between these two quantities [42° 37′ and 42° 48′]. The number required in example is therefore 92+0·6=92·6.

Rule for Use of Tables I. and II.

From Table I. take value of N for the given Hour Angle, and multiply it by 10. From Table II. take T for approximate latitude and for declination; add if unlike, subtract if like. Divide 10N by this sum or difference. The result is the correction in minutes and decimals, additive to the altitude.

Combined Correction to Observed Altitude for H.E., Sun's Semi-diameter and Refraction.

☉	Height of Eye :—Feet.				
	20	**25**	**30**	**35**	**40**
°	′	′	′	′	′
10	6·4	5·9	5·4	4·8	4·2
11	6·9	6·4	5·9	5·3	4·7
12	7·3	6·8	6·3	5 7	5·1
13	7·6	7·1	6·6	6·0	5·4
14	7·9	7·4	6·9	6·3	5·7
15	8·2	7·7	7·2	6·6	6·0
16	8·4	7·9	7·4	6·8	6·2
17	8·6	8·1	7·6	7·0	6·4
18	8·8	8·3	7·8	7·2	6·6
19	8·9	8·4	8·0	7·4	6·8
20	9·1	8·6	8·1	7·5	6·9
22	9·4	8·9	8·4	7·8	7·2
24	9·6	9·1	8·6	8·0	7·4
26	9·8	9·2	8·8	8·2	7·6
28	9·9	9·4	8·9	8·3	7·7
30	10·1	9·5	9·1	8·5	7·9
34	10·3	9·8	9·3	8·7	8·1
38	10·5	10·0	9·5	8·9	8·3
42	10·6	10·1	9·7	9·1	8·5
46	10·8	10·3	9·8	9·2	8·6
50	10·9	10·4	9·9	9·3	8·7
55	11·0	10·5	10·0	9·4	8·8
60	11·1	10·6	10·1	9·5	8·9
70	11·3	10·8	10·3	9·7	9·1

Add the Correction to the Obs., Alt., Sun's L.L. If great accuracy is required use also the next Table.

For a star, subtract 16′·0 after applying first correction.

1—15.		16—31.
′		′
+ ·3	Jan.	+ ·3
+ ·2	Feb.	+ ·2
+ ·1	Mar.	+ ·1
·0	April	− ·1
− ·1	May	− ·2
− ·2	June	− ·2
− ·2	July	− ·2
− ·2	Aug.	− ·1
− ·1	Sept.	·0
+ ·1	Oct.	+ ·1
+ ·2	Nov.	+ ·2
+ ·3	Dec.	+ ·3

(12) The Sextant.

The errors inherent in the sextant and its use may be divided into three classes, viz. :—

(*a*) Adjustable Errors.
(*b*) Non-adjustable Errors.
(*c*) Observer's Errors.

(*a*) Adjustable Errors

(1) **That the Telescope is in true focus.**

The telescope should be focussed on infinity. Focus on a very distant object; the Moon is best. Mark the telescope draw-tube, that it may be correctly set at any time.

(2) **That the Index Glass is perpendicular to the plane of the instrument.**

To correct—Look obliquely into the Index Glass to view the True and Reflected arcs together: if the True and Reflected arcs are in one straight line, the Index Glass is perpendicular; if not, adjust till correct with the screw at the back of the Index Glass.

(3) **That the telescope receives the proper proportions of light from the silvered and unsilvered portions of the Horizon Glass.**

Observe a distant object with the radius bar nearly at zero; the Moon is best. Move the telescope up or down, by the screw giving motion to the telescope collar perpendicularly to the instrument, until the True and Reflected objects are of equal brightness.

Mark the collar pillar at the adjustment, so that it may be correctly set at any time.

(4) **That the Horizon Glass is perpendicular to the plane of the instrument.**

To correct—View a distant object, such as the Sun or a Star, with the radius bar at or near zero. If the True and Reflected objects pass directly the one over the other when the radius bar is moved to and fro, the Horizon Glass is perpendicular. If not, adjust till correct with the screw at the back of the Index Glass.

(5) **That the optical axis of the Telescope is parallel to the plane of the instrument.**

To correct—Set the telescope with two of the wires in the field parallel to the plane of the instrument. Measure the angle between two distant objects, such as Stars, making contact first on one wire and then on the other. If contact between the objects is preserved on both wires, the optical axis is parallel to the plane of the instrument; if not, adjust with the screws on the telescope holder till contact at both wires is preserved.

Note.—Adjustment (3) should now be repeated if the telescope screws are moved or if the horizon Glass required adjustment.

(6) **"Index Error," or the reading on or off the arc when the Horizon Glass is parallel to the Index Glass.**

Methods of measuring Index Error.

(*a*) **By Sun's diameter on and off the arc.**

Measure the Sun's diameter on and off the arc by bringing the limbs of the True and Reflected Suns into contact first on one side and then on the other.

The Index Error is half the difference of the two readings, and is—

Added to all observed angles if the greatest reading is off the arc or to the right of zero.

Subtracted from all observed angles if the greatest reading is on the arc or to the left of zero.

Note (1).—The sum of the readings divided by 4, if accurately observed, should equal the semi-diameter of the Sun for the day given in the Nautical Almanac.

Note (2).—Care should be taken that the True and Reflected Suns are of equal brightness.

(*b*) **By a Star.**

Move the radius bar till the True and Reflected Stars coincide.

The Index Error is the reading obtained on coincidence, + if to the Right, − if to the Left of zero.

(*c*) **By the Sea Horizon.**

View the Horizon through the eye-piece, moving the radius bar till the True and Reflected Horizons coincide.

The Index Error is the reading obtained on coincidence, + if to the Right, − if to the Left of zero.

(*b*) Non-adjustable Errors

(1) **Centering Error.**—This comprises :—

(*a*) The pivot centre of the radius bar not coinciding with the arc.
(*b*) The circular arc in the plane of the instrument bent or distorted.
(*c*) The pivot axis of the radius bar not lying wholly in the plane of the reflecting surface of the Index Glass.

Centering Error is determined by special apparatus at the National Physical Laboratory or at Kew Observatory, to which places sextants should frequently be sent for examination.

To endeavour to determine Centering Error by observations would include personal errors and be unreliable.

(2) **Graduation Error.**

This is faulty graduation of the arc in process of manufacture, and should be non-existent. It would generally become included in Centering Error.

(3) **Vernier Error.**

The extremities of the vernier should exactly coincide with the correct divisions on the arc. If error exists, the instrument should be returned to the makers for a new vernier, or readjustment of the vernier on the arc.

(4) **Shade Error.**—See also Personal Error.

The back and front surfaces of the coloured shades must be perfectly parallel, otherwise diffraction, as in a prism, will arise.

This can be corrected by turning the shades in their holders till the edge of the prism formed by the planes of the surfaces is perpendicular to the plane of the instrument.

The existence of Shade Error may be determined by bringing a True and Reflected Sun into contact, and then altering the combination of shades and noting if the contact varies; or by comparing a contact made using the shades, with a contact made using a coloured glass eye-piece on the telescope.

This only determines the existence of shade error, and not the shade in error.

As only Index Glass shades are generally used in measuring altitudes, the error is difficult to eliminate and is a matter for the manufacturers to remove.

(5) **Parallelism of surfaces of Index Glass and of surfaces of Horizon Glass.**

The back and front surfaces of both the Index Glass and Horizon Glass must be perfectly parallel. Error in this parallelism would cause the Index Error to vary with the angle measured. This error is practically determined with and included in the Centering Error determined at the testing laboratories.

(*c*) Observer's Errors

(1) **Irradiation.**

Irradiation is the apparent magnification of a body when it is too bright. Care should therefore be taken to use as dark shades as will enable the body to be easily seen.

(2) **Personal Error.**

This may be an overlapping contact or no true contact when measuring altitudes, etc. Personal Error is reduced by practice, but probably varies with every observation.

The error may be roughly ascertained by measuring a Meridian Altitude through the Pole and Zenith of the observer to the opposite horizon to that giving the maximum altitude. This angle must be less than 130°.

Directly this Meridian Altitude is observed, an Ex Meridian Altitude of the same body should be taken in the usual manner and reduced to the Meridian Altitude as in Ex Mer. Alt. observations.

Both altitudes, corrected for Centering Error, Index Error, Dip, Refraction, Parallax, and Semi-diameter, should, when added together, $=180°$.

If the sum is less or more than 180°, half the excess or deficit may be taken as the Personal Error and Shade Error combined.

The observer must be stationary.

FIG. 19.

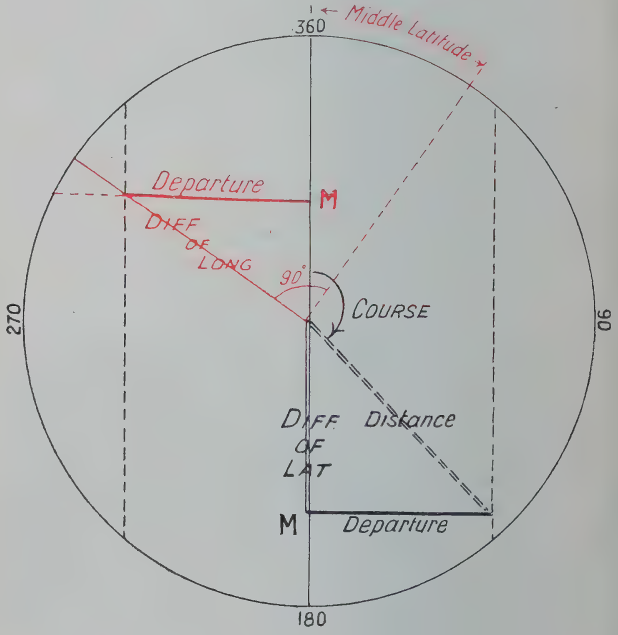
Plane Sailing—Black.

Middle Lat. Sailing—Red.

Sine Course = Departure ÷ Distance.
Cosine Course = Diff. of Lat. ÷ Distance.
Tangent Course = Departure ÷ Diff. of Lat.

Mid. Lat. Sailing. Cosine Mid. Lat. = Departure ÷ Diff. of Long.

N.B.—Diff. Lat., Departure, Distance, and Diff. Long. are all measured on the same unit of length.



(13) The Sailings

The employment of the Sailings for practical navigation is almost obsolete. The methods of the present day are to lay off Courses, Distances, Differences of Latitude or Differences of Longitude on Mercator's Charts, and to measure the resulting Latitudes on the scales of Latitude on the sides of the chart, and Longitudes on the scales of Longitude at the top and bottom of the chart.

The Sailings are four, viz. :—

(*a*) Plane Sailing.
(*b*) Middle Latitude Sailing.
(*c*) Mercator's Sailing.
(*d*) Parallel Sailing.

Definitions

A Rhumb Line is a curve joining two places and cutting all meridians at the same angle.

On a Mercator's Chart a Rhumb line is a straight line, as the meridians are parallel.

The Course is the angle the Rhumb line sailed on makes with the meridians, and is measured clockwise through 360° from zero at North.

The Distance is the number of nautical miles sailed along the Rhumb line.

The Difference of Latitude (D. Lat.) is the number of nautical miles made good in a direction due N. or due S.

The Meridional Difference of Latitude (M.D. Lat.) is the length on a Mercator's Chart representing the difference of Latitude between two places.

The Departure is the number of nautical miles made good in a direction due E. or W.

The Difference of Longitude is the arc of the equator intercepted between the meridians passing through the two places and corresponding at the equator to the amount of Departure.

The Middle Latitude is the mean of the Latitudes of the two places.

The True Middle Latitude is the Latitude whose cosine is equal to the Departure divided by the Difference of Longitude.

(*a*) Plane Sailing

In Plane Sailing, the use of which is only correct for moderate distances, the ship is regarded as sailing on a plane surface, the curvature of the Earth being neglected. The quantities involved—the Course, Distance, D. Lat., and Dep.—are connected in a plane right-angled triangle.

The Distance is the hypothenuse.
,, Diff. Lat. ,, base.
,, Departure ,, perpendicular.

These three quantities are measured in terms of the same unit of length, which is not the case in Mercator's Sailing.

By means of the Traverse Table, and knowing any two of the above four quantities, the other two quantities can be obtained by inspection.

Or graphically, as in fig. 19, having laid off any two of the above quantities, the other two can be found.

Or by Trigonometrical ratios:

Sine Course = Departure ÷ Distance.
Cosine Course = Diff. of Lat. ÷ Distance.
Tangent Course = Departure ÷ Diff. of Lat.

The D. Lat. applied to the Lat. of Departure gives the Lat. of Destination.

The Dep. must be converted to D. Long. by the formula of Mid. Lat. Sailing.

Then the D. Long. applied to the Long. of Departure gives the Long. of Destination.

(*b*) **Middle Latitude Sailing**

Middle Latitude Sailing is an approximation near enough for all practical purposes. The proof lies in the principle of Parallel Sailing.

Taking the Middle Latitude between two places as the mean of the Latitudes of the two places,

D. Long. = Departure × Secant Middle Latitude.

Hence, having found by Plane Sailing the Departure and Middle Latitude, the Diff. of Long. can be found and applied to the Longitude of the Departure point, thus giving the Longitude of the Destination point.

(*c*) **Mercator's Sailing**

In Mercator's Sailing the ship is regarded as sailing on the Earth's surface as represented by a Mercator's Chart, and the results obtained are exact, and not approximately correct as in Plane Sailing.

The quantities involved—the Course, the Distance and Meridional Difference of Latitude (both measured on the same scale of Meridional Latitude), and the Diff. of Long. measured on the Longitude Scale—are connected in a plane right-angled triangle where

The Distance is the Hypothenuse.
,, M.D. Lat. ,, Base.
,, D. Long. ,, Perpendicular.

[*To face p.* 164.

FIG. 20.

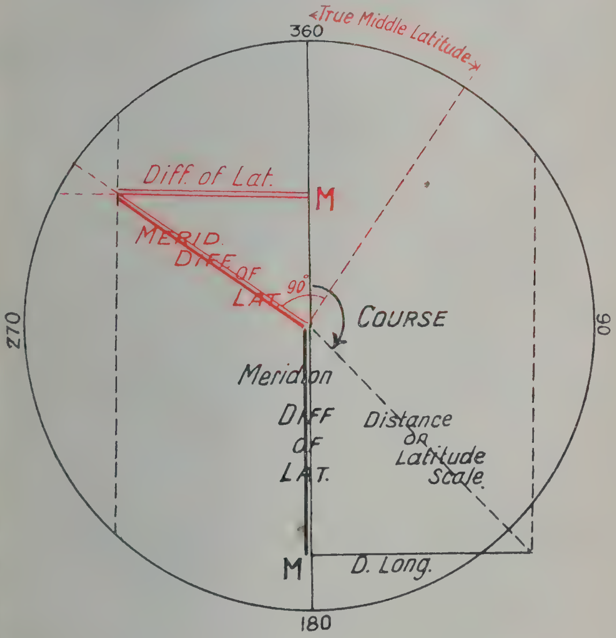
Mercator's Sailing.

Tan Course = Diff. of Long. ÷ Merid. Diff. of Lat.

Cos. True Mid. Lat. = Diff. of Lat. ÷ Merid. Diff. of Lat

N.B.—The unit of length for Distance and Mer. Diff. Lat. varies with the Latitude. Both must be measured on the Mer. Diff. Lat. Scale.

Diff. Long. and Diff. Lat. have a constant unit of length and are measured on the Longitude Scale.



The Distance and Mer. D. Lat. are measured on the Meridional Difference of Latitude scale between the Latitude of Departure and Latitude of Destination, as this scale varies with every Latitude.

The D. Long. is measured on the D. Long. scale, which does not vary with the Latitude.

Thus, though the above quantities are related in the same right-angled triangle, care must be taken to measure their values on the correct scales.

From the right-angled triangle (*v.* fig. 20) the formula obtained is:

$$\text{Tangent Course} = \text{Diff. Long.} \div \text{Mer. D. Lat.}$$

The use of the above formula is that, given the Latitude and Longitude of the Departure point and the Latitude and Longitude of the Destination point, the True Course to steer and the Distance to travel can be accurately ascertained, taking into account the curvature of the Earth.

Tables of Meridional Parts are given in Inman's Tables and other similar publications.

True Middle Latitude

The True Middle Latitude between two places is the Latitude whose cosine = ratio $\frac{\text{Departure}}{\text{Diff. of Long.}}$, and it is in most cases nearly equal to the Middle Latitude between the two places, but a more strictly accurate value is as above.

Now, as on a Mercator's Chart the Departure between two places is expanded to equal the length representing the D. Long. between these two places, so also is the Difference of Latitude between the two places expanded to the length representing the Meridional Difference of Latitude, thus:

$$\frac{\text{Departure}}{\text{Diff. Long.}} = \frac{\text{D. Lat.}}{\text{Mer. D. Lat.}} = \text{Cosine True Middle Latitude.}$$

Thus the True Middle Latitude between two places can be found, and with the True Middle Latitude and Departure the D. Long. can be accurately found, for

$$\text{D. Long.} = \text{Departure} \times \text{Secant True Middle Latitude.}$$

From the formulæ

$$\text{Tangent Course} = \text{D. Long.} \div \text{Mer. D. Lat.}$$
$$\text{Cosine True Mid. Lat.} = \text{D. Lat.} \div \text{Mer. D. Lat.}$$

we obtain

$$\frac{\text{Tangent Course}}{\text{Cosine True Mid. Lat.}} = \frac{\text{D. Long.}}{\text{D. Lat.}}$$

(*d*) Parallel Sailing

In Parallel Sailing a ship sails due E. or due W. on the arc of a parallel of Latitude; hence the Departure and Distance are the same and equal, and there is no D. Lat.

The property of a sphere (which will be demonstrated) here obtains, viz. :—

The arc of a small circle $\div$ the corresponding arc of a great circle on the same sphere and parallel to it, is equal to the cosine of the arc normal intercepted between these two circles; hence

$$\text{Departure or Distance} = \text{Diff. of Long.} \times \text{Cosine Latitude.}$$

This can be determined graphically in fig. 19 in the triangle in red, where

the Latitude	is laid off as the		Middle Latitude.
,, Diff. Long.	,,	,,	hypothenuse shown.
,, Departure	,,	,,	base as shown.

PART II

SPHERICAL PROJECTION

PROOFS OF FORMULÆ
AND USE OF THE SPHERICAL DIAGRAM

GREAT CIRCLE SAILING

AND

NAUTICAL ASTRONOMY

NOTE.

To use the Spherical Diagram it is only necessary to read the instructions lined on the margin.

CONTENTS

SECTION (b).—GREAT CIRCLE SAILING

SECTION (c).—NAUTICAL ASTRONOMY

INTRODUCTORY REMARKS

HEREIN the principles of the Theory of Navigation and Nautical Astronomy are demonstrated graphically.

Proofs of formulæ already used are given, and the means by which, given certain quantities, other quantities related to the former can be determined graphically, is shown.

For graphic solution of problems the True Compass printed on Admiralty Charts is suitable, but, for greater rapidity and accuracy, "Grant's Plotting Board for the Solution of Tactical Problems" is better.

With a pair of compasses, an angle protractor, and a straight-edge only all these problems can be solved, though somewhat tediously.

The Spherical Diagram, to be explained later, is, however, the simplest and most rapid means of solving all problems.

These methods of solving spherical problems are especially useful for the determination of—

(1) Quantities used in Great Circle Sailing.
(2) Hour Angles, Declinations, or Altitudes of Stars and Planets, with sufficient accuracy to ensure the identification of any particular star or planet.
(3) Azimuths of all Heavenly Bodies, with sufficient accuracy to determine positions by Marc St Hilaire's method.
(4) Times of Rising and Setting of all Heavenly Bodies.
(5) The duration of Twilight, etc.

The Spherical Diagram enables the above quantities to be determined on a diagram of 5 inches radius with an accuracy equal to the Azimuth and Great Circle Tables extant, and with equal rapidity.

This saves the necessity of purchasing expensive books of Azimuth Tables, etc., and is a great economy in bulk of books necessary for navigation.

The particular value of these graphic methods is that they give clear mental pictures of the geometry of a sphere, and thereby lead to a clear understanding of the principles of Great Circle Sailing and Nautical Astronomy. Formulæ are readily deduced and understood, and intricate proofs are avoided.

A knowledge of the simple trigonometrical ratios of plane trigonometry is all that is required.

SECTION (a)

Spherical Projection

Imagine an observer to view a sphere from an infinite distance, and let the hemisphere presented towards him be transparent. This hemisphere will appear as a flat circular surface, and the line from the observer's eye to its centre will be perpendicular, or normal to this surface.

The plane circular surface thus presented is termed the "Plane of Projection," and written "P. of P." for brevity.

Imagine also that the transparent hemisphere has marked on its surface certain Great and Small Circles, which will then appear as marked—or, as it is commonly termed, "projected"—on the P. of P.

These Great and Small Circles will appear as straight lines or curves on the P. of P., according as the planes of these circles are normal or inclined to the P. of P.

Such projections of Great and Small Circles will now be investigated, and more particularly the projection of their points of intersection.

Great Circles of the surface of a sphere form planes passing through the centre of the sphere.

Small Circles of the surface of a sphere form planes not passing through the centre of the sphere.

(1) Let PQP′Q′ be the circle presented to an observer by the transparent hemisphere of a sphere at an infinite distance. Then PQP′Q′ is the P. of P. (Fig. 1.)

Let C be the centre of the P. of P. C consequently is also the centre of the sphere.

(2) Let PP′ be a diameter of the P. of P. PP′ consequently passes through C.

(3) **All Great Circles whose planes are perpendicular** to the P. of P. will, it is evident, appear projected as straight lines, diameters of the circle PQP′Q′.

Let QQ′ be the projection of such a Great Circle whose plane is also perpendicular to the diameter PP′. Then PP′ and QQ′ intersect at C at right angles. (Fig. 1.)

(4) **All Small Circles whose planes are perpendicular** to the P. of P. will, it is evident, appear projected as straight lines, parallel to the diameter representing the projection of that Great Circle to which their planes are parallel.

Let pp' be the projection of such a Small Circle whose plane is parallel to the plane of the Great Circle QQ′ and whose circumference is distant $p°$ from the pole P of QQ′. Then Pp or P$p' = p°$.

QQ′ is termed the Equator of pp' or of any other Small Circle that is parallel to it. (Fig. 3.)

(5) **Great Circles whose planes are not perpendicular** to the

P. of P. will project as curves called "Ellipses," each meeting, at opposite ends of a diameter, the circumference of the P. of P.

The planes of all Great Circles of a sphere intersect each other on diameters of the sphere. The diameter of the intersection of any two is called the "Common Diameter."

Let PT′P′ (fig. 1) be the projection of the circumference of a Great Circle whose plane cuts the P. of P. along the diameter PCP′ and is inclined to the P. of P. at an angle of $t°$.

Problem I

(Figs. 1 and 2)

To project the intersection of the arcs of two Great Circles whose planes are perpendicular to one another, where the plane of one Great Circle is perpendicular to the P. of P., and the plane of the other inclined at an angle ($t°$) to the P. of P.

Let QQ′ be the projection on the P. of P. of a Great Circle whose plane is perpendicular to the P. of P.

Let PT″P′ be a semicircular plane and suppose it to revolve, as if hinged along the line PP′, from a position lying on and coincident with the plane PCP′Q of the P. of P.

If PT″P′ revolves through 90° it is perpendicular to the P. of P., and its projection would be represented by PP′ cutting QQ′ at C.

If PT″P′ revolves through 180° it would be coincident with the plane PCP′Q′ of the P. of P., and its arc would cut the arc of QQ′ at Q′.

At all other angles the projection of PT″P′ would present a curve passing through P and P′ as shown, but the radius CT″ would still be a radius of the sphere and equal to CQ or CQ′.

(*a*) In fig. 1, where the P. of P. is viewed normally from an infinite distance, let a radius CT revolve from CQ to trace out an angle $QCT = t°$.

Draw TT′ perpendicular to QQ′.

Now Cosine $QCT = \text{cosine } t° = \dfrac{CT'}{CT} = \dfrac{CT'}{r}$, where r is the radius of the sphere. (1)

(*b*) In fig. 2, where the P. of P. is viewed edge on from an infinite distance, the eye being on the line PP′ produced towards P′, the P. of P. appears as the straight line QQ′, and the plane PT″P′ as the straight line CT″ meeting QQ′ at its middle point and making an angle with it $QCT'' = t°$.

Draw T″T′ perpendicular to QQ′, and therefore perpendicular to the P. of P.

Now Cosine $QCT'' = \text{cosine } t° = \dfrac{CT'}{CT''} = \dfrac{CT'}{r}$, where r is the radius of the sphere. (2)

Also, T″T′ being perpendicular to the P. of P., T′ is the projection of T″, the intersection of the arcs of the Great Circles PT″P′ and QEQ′.

(*c*) From (1) and (2) it is clear that the point T′ constructed as in (1) coincides with the point T′ projected as in (2).

Hence, if the angle $t°$ made by the plane PT″P′ with the P. of P. is represented by the angle QCT laid off from the radius CQ at right angles to PP′, the hinge of the plane PT″P′, then a perpendicular from T cuts QQ′ at the projection of the intersection of the arcs of PT″P′ and QEQ′.

FIG. 1.

Plan on Plane of Great Circle of a Sphere.

(Eye at an infinite distance vertically above C.)

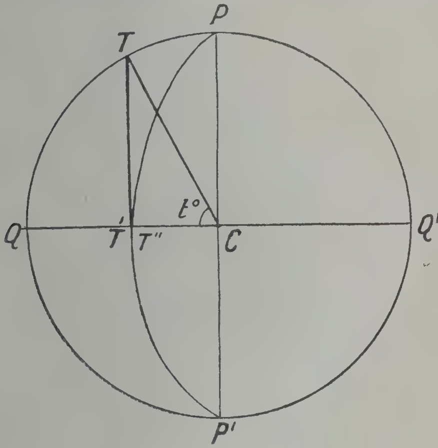
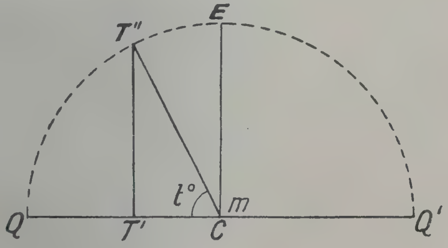


FIG. 2.

Plan on Plane of Great Circle QQ′.

(Eye at an infinite distance on axis PP′ on side of P′.)



[To face p. 177.

FIG. 3.

Problems II., IV., and V.

Examples 1, 2, *and* 3. *Sections* (*b*) *and* (*c*).

Projection of intersection of Small and Great Circles (planes at right angles).

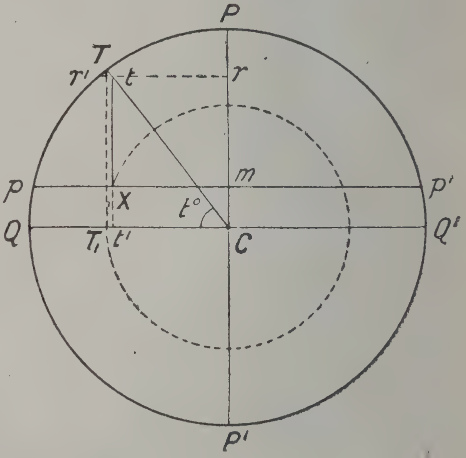


FIG. 4.

Plan on Plane of Small Circle pp'.

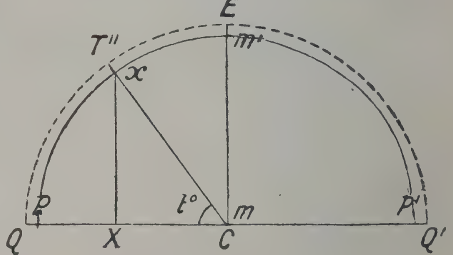


FIG. 3*a*.

Problems II., IV., and V.

Examples 4, 5, *and* 6. *Sections* (*b*) *and* (*c*).

Projection of intersection of Small and Great Circles (planes at right angles).

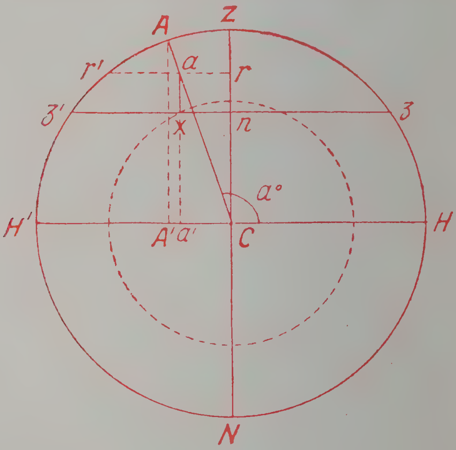
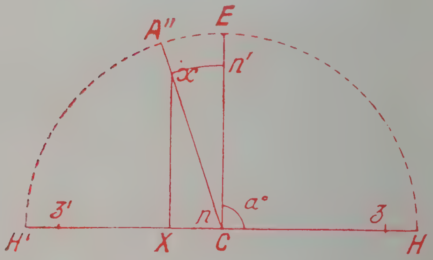


FIG. 4*a*.

Plan on Plane of Small Circle *zz'*.



Problem II (Figs. 3 and 4 and 3*a* and 4*a*)

To project the intersection of the arcs of a Small Circle and of a Great Circle whose planes are perpendicular to one another, where the plane of Small Circle is perpendicular to the P. of P. and its arc distant $p°$ from the pole of its equator, the plane of the Great Circle being inclined at an angle $t°$ to the P. of P.

Let PxP′ (fig. 3) be a Great Circle whose plane is inclined at an angle of $t°$ to the P. of P.

Let pp' be a Small Circle whose plane is perpendicular to the planes of the P. of P. and of the Great Circle PxP′, and whose arc is distant $p°$ from P, the pole of the Great Circle QQ′ to the plane of which the plane of pp' is parallel.

The Small Circle pp' will be referred to as the Parallel pp'.

Let x be the intersection of the arcs of the Great Circle PxP′ and the parallel pp'.

Let m be the middle point of the chord pp', then m is the centre of the parallel pxp'.

As x is a point on the circumference of the parallel pp', mx is a radius of the parallel pp' and is equal to mp or mp' (*v.* fig. 4).

(*a*) In fig. 3, where the P. of P. is viewed normally from an infinite distance, let a radius CT revolve from CQ to trace out an angle QCT$=t°$.

Make C$t=mp$ and draw tXt' perpendicular to and meeting pp' and QQ′ in X and t' respectively.

Now Cosine QCT$=$cosine $t°=\mathrm{C}t'/\mathrm{C}t=m\mathrm{X}/mp=m\mathrm{X}/r_1$, where r_1 is the radius of pxp'. (1)

(*b*) In fig. 4, where the P. of P. is viewed edge on from an infinite distance, the eye being on the line PP′ produced towards P′, the P. of P. appears as the straight line Qpp'Q′, and the plane PxP′ as the straight line mx meeting pp' at its middle point m, and inclined to QQ′ at an angle QC$x=t°$.

Draw xX perpendicular to pmp', and hence perpendicular to the P. of P.

Now Cosine $pmx=$cosine $t°=m\mathrm{X}/mx=m\mathrm{X}/r_1$, where r_1 is the radius of pxp'. (2)

Also, xX being perpendicular to the P. of P., X is the projection of x, the intersection of the arcs of the Great Circle PxP′ and the parallel pxp'.

(*c*) From (1) and (2) it is clear that the point X constructed as in (1) coincides with the point X projected as in (2).

Hence if the angle $t°$ made by the plane PxP′ with the P. of P. is represented by the angle QCT laid off from the radius CQ, and if Ct is cut off along CT$=mp$ or mp' (half the chord pp' or the radius of the parallel pp') and tX is drawn perpendicular to pp' meeting it in X, then X is the projection of the intersection of the arcs of PxP′ and pxp'.

This problem is the basis of the Examples 1 to 10, Section (*b*).

Problem III

(Fig. 5: Examples 9, Sections (*b*) and (*c*))

To project the intersection of the arcs of two Small Circles whose planes are perpendicular to the P. of P. and inclined to one another at an angle of $c°$, the arcs of these Small Circles being distant $p°$ and $z°$ respectively from the poles of their equators.

Let P be the pole of QQ′, the equator of the Small Circle pp'.

Make Pp or P$p' = p°$, and rule pp' perpendicular to CP.

Let PCZ $= c°$. Then Z is the pole of the equator HH′ of the second Small Circle.

Make Zz or Z$z' = z°$, and rule zz' perpendicular to CZ.

Now the planes of both Small Circles are perpendicular to the P. of P., therefore pp' and zz' are the projections of their arcs. Let pp' and zz' intersect at X.

Then X is the required projection of the intersection of these arcs.

Problem IV

(Figs. 3, 3*a*, and 5: Examples 1 to 10, Sections (*b*) and (*c*))

The Projection of a Spherical Triangle

Figs. 3 and 4 show the projection of the intersection of the arcs of a Great Circle and of a Small Circle, where the plane of the Great Circle PxT″P′ is inclined at an angle of $t°$ to the P. of P., and the plane of the Small Circle pxp' is perpendicular to PxT″P′ and the P. of P.

The arc of pp' is $p°$ from P, therefore P$x = p°$. Let pp' cut PP′ in m (fig. 5).

Figs. 3*a* and 4*a* show the projection of the intersection of the arcs of a Great Circle and of a Small Circle, where the plane of the Great Circle ZxA″N′ is inclined at an angle of $a°$ to the P. of P., and the plane of the Small Circle zxz' is perpendicular to ZxA″N and the P. of P.

The arc of zz' is $z°$ from Z, therefore Z$x = z°$. Let zz' cut ZN in n (fig. 5).

In each projection let the radius CX be the same. Then if fig. 3*a* is laid on fig. 3 with the centres C, and the points X, respectively coincident, PZX (*v.* fig. 5) is the projection of a spherical triangle PZx, where—

The angle ZP$x = t°$ or the inclination of PT″P′ to the P. of P.
,, ,, PZ$x = a°$,, ,, ,, ZA″N′ ,, ,,
,, ,, ZxP $= x°$,, ,, ,, PT″P′ to ZA″N.
,, side Px $= p°$, where $p° =$ the distance of pp' from P.
,, ,, Zx $= z°$, ,, $z° =$,, ,, zz' ,, Z.
,, ,, PZ $= c°$, ,, $c° =$ the angle between the hinges of PT″P′ and ZA″N.

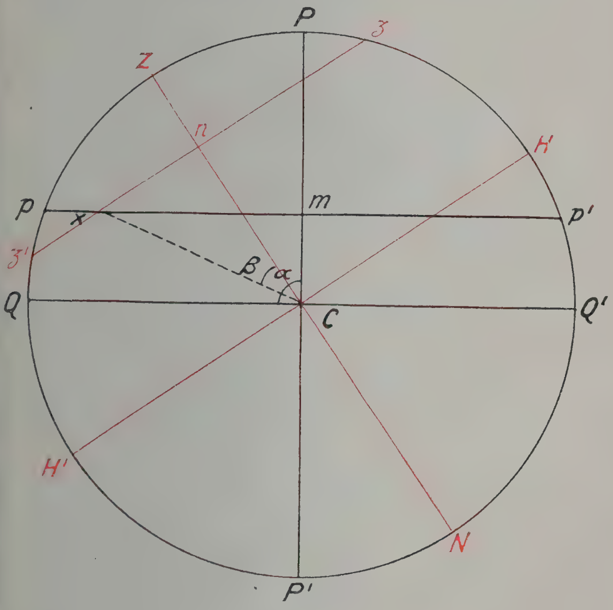
[*To face p.* 178.

FIG. 5.

Problems III., IV., and V.

Examples 1 *to* 6 *and* 9. *Sections* (*b*) *and* (*c*).

Projection of intersection of arcs of two Small Circles.



In the diagrams the following equalities should be noted :—

(1) The half chords rr' through t or a respectively parallel to the Small Circles pp' or $zz'=$CX (*v.* figs. 3 and 3*a*).
Let the radius of the sphere $=$R.
Then $Cr'^2 = rr'^2 + rC^2 = pm^2 + mC^2 = tC^2 + mC^2 = tr^2 + rC^2 + CX^2 - Xm^2$. Hence $rr'^2 = CX^2$, or $rr' = CX$ (in fig. 3).
Similarly, $rr' = CX$ (in fig. 3*a*).

(2) From above, $R^2 = CX^2 + t't^2$ in fig. 3, and $R^2 = CX^2 + a'a^2$ in fig. 3*a*.

(3) From above, if CX is equal in both projections, as in fig. 5, then $tt' = aa'$.

Problem V

The Formulæ of a Spherical Triangle

The following equalities in the projection of a spherical triangle must be noted :—

Let the radius (R) of the sphere be unity. then in figs. 3 and 3*a*—

(1) $\frac{1}{2}pp' = pm = Ct = \text{sine } p^\circ$, and $\frac{1}{2}zz' = zn = Ca = \text{sine } z^\circ$.

(2) $Cm = \text{cosine } p^\circ$, and $Cn = \text{cosine } z^\circ$.

(3) $Xm = Ct' = Ct \text{ cosine } t^\circ = \text{sine } p^\circ \text{ cosine } t^\circ$.
$Xn = Ca' = -Ca \text{ cosine } a^\circ = -\text{sine } z^\circ \text{ cosine } a^\circ$.

(*a*) The Sine Formulæ

From Problem II., figs. 3 and 5,

$$Xm = \text{sine } p^\circ \text{ cosine } t^\circ, \quad \text{and} \quad mC = \text{cosine } p^\circ;$$

also $$CX^2 = Xm^2 + mC^2 = \text{sine}^2\, p^\circ \text{ cosine}^2\, t^\circ + \text{cosine}^2\, p^\circ. \tag{1}$$

From Problem II., figs. 3*a* and 5,

$$Xn = -\text{sine } z^\circ \text{ cosine } a^\circ, \quad \text{and} \quad nC = \text{cosine } z^\circ;$$

also $$CX^2 = Xn^2 + nC^2 = \text{sine}^2\, z^\circ \text{ cosine}^2\, a^\circ + \text{cosine}^2\, z^\circ. \tag{2}$$

Equating (1) and (2),

$$\text{sine}^2\, p^\circ(1 - \text{sine}^2\, t^\circ) + \text{cosine}^2\, p^\circ = \text{sine}^2\, z^\circ(1 - \text{sine}^2\, a^\circ) + \text{cosine}^2\, z^\circ.$$

Therefore $$\text{sine}^2\, p^\circ \text{ sine}^2\, t^\circ = \text{sine}^2\, z^\circ \text{ sine}^2\, a^\circ.$$

Hence $$\frac{\text{sine } t^\circ}{\text{sine } z^\circ} = \frac{\text{sine } a^\circ}{\text{sine } p^\circ}, \text{ and by analogy} = \frac{\text{sine } x^\circ}{\text{sine } c^\circ}.$$

(*b*) The Fundamental Formulæ

(Three sides and one angle)

In fig. 5, join CX and let angle $XCm=\alpha$, $XCn=\beta$, then angle $PCZ=c=(\alpha-\beta)$.

Now $\quad \text{cosine } z^\circ = nC\left(\dfrac{Xm^2+mC^2}{CX^2}\right)$, for $CX^2=Xm^2+mC^2$.

Insert $\dfrac{1}{CX^2}(nX\,.\,Xm\,.\,mC-nX\,.\,Xm\,.\,mC)$, which is zero.

Then

$$\text{cosine } z^\circ = mC\left(\frac{mC\,.\,Cn}{CX\,.\,CX}+\frac{mX\,.\,Xn}{CX\,.\,CX}\right)+Xm\left(\frac{Xm\,.\,nC}{CX\,.\,CX}-\frac{mC\,.\,Xn}{CX\,.\,CX}\right)$$

$$=mC \text{ cosine } (\alpha-\beta)+Xm \text{ sine } (\alpha-\beta).$$

Therefore

$$\text{cosine } z^\circ=\text{cosine } p^\circ \text{ cosine } c^\circ+\text{sine } p^\circ \text{ sine } c^\circ \text{ cosine } t^\circ.$$

Similarly,

$$\text{cosine } p^\circ=\text{cosine } z^\circ \text{ cosine } c^\circ+\text{sine } z^\circ \text{ sine } c^\circ \text{ cosine } a^\circ.$$

By analogy,

$$\text{cosine } c^\circ=\text{cosine } p^\circ \text{ cosine } z^\circ+\text{sine } p^\circ \text{ sine } z^\circ \text{ cosine } x^\circ.$$

(*c*) The Fundamental Formulæ

(Three angles and one side)

Now $\text{cosine } x^\circ=\dfrac{\text{cosine } c^\circ-\text{cosine } p^\circ \text{ cosine } z^\circ}{\text{sine } p^\circ \text{ sine } z^\circ}$ (from § (*b*) above

$$=\frac{(CX^2+tt'^2)\text{ cosine } c^\circ-mC\,.\,nC}{Ct\,.\,Ca} \text{ for } \begin{cases} CX^2+tt'^2=1 \\ c^\circ=(\alpha^\circ-\beta^\circ) \\ tt'^2=tt'\,.\,aa' \end{cases}$$

$$=\frac{1}{Ct\,.\,Ca}\left(CX^2\frac{mC\,.\,Cn+mX\,.\,Xn}{CX^2}+tt'\,.\,aa'\,.\text{ cosine } c^\circ-mC\,.\,Cn\right)$$

$$=\frac{mX\,.\,Xn}{Ct\,.\,Ca}-\frac{tt'\,.\,aa'}{Ct\,.\,Ca}\text{ cosine } c^\circ, \text{ but } \frac{Xn}{Ca}=-\text{cosine } a^\circ.$$

Therefore

$$\text{cosine } x^\circ=-\text{cosine } t^\circ \text{ cosine } a^\circ+\text{sine } t^\circ \text{ sine } a^\circ \text{ cosine } c^\circ.$$

Similarly,

$$\text{cosine } a^\circ=-\text{cosine } t^\circ \text{ cosine } x^\circ+\text{sine } t^\circ \text{ sine } x^\circ \text{ cosine } p^\circ.$$

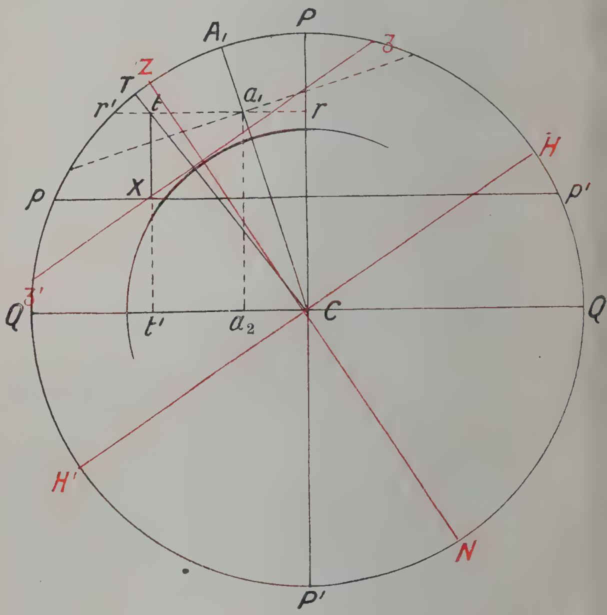
Also, $\text{cosine } t^\circ=-\text{cosine } a^\circ \text{ cosine } x^\circ+\text{sine } t^\circ \text{ sine } x^\circ \text{ cosine } z^\circ$

FIG. 6.

Problem VI.

Examples 3 *and* 6. *Sections* (*b*) *and* (*c*).

Small and Great Circles (planes perpendicular) intersecting at a given point.



Problem VI (Fig. 6: Examples 3 and 6, Sections (*b*) and (*c*))

To project the plane of a Small Circle whose plane is perpendicular to the P. of P. and to the plane of a Great Circle inclined at $a°$ to the P. of P., where the arcs of both this Small Circle and Great Circle pass through a given point, the given point being determined by the intersection of the arcs of another Small Circle and Great Circle fulfilling the conditions of Problem II.

Let X be the projection, found as in Problem II., of the intersection of the arcs of a Small Circle pp' and of a Great Circle PT′P′ whose planes are perpendicular to one another, where the plane of pp' is perpendicular to the P. of P., and its arc distant $p°$ from P, hence $Px = p°$, and the plane of the Great Circle is inclined at an angle $QCT = t°$ to the P. of P.

Let $Q'CA_1$ be the inclination $a°$ of the plane of a Great Circle passing through x.

Construction (fig. 6)

Through t (*v.* Problem II.) draw ta_1r parallel to QQ′, meeting CA_1 in a_1 and PP′ in r.

Through a_1 rule a chord perpendicular to CA_1, and with radius equal to half this chord describe about C a circle.

Through X rule a chord zz' touching the circle.

Then zz' is the projection of the required Small Circle.

Let perpendiculars from t and a_1 to QQ′ meet QQ′ in t' and a_2 respectively.

Argument

The point X is the projection of the Great Circle inclined at an angle $t°$ to the P. of P. and of the Small Circle pp'.

X is also on the projection of the Small Circle zz', which, if at right angles to the Great Circle inclined at an angle $a°$ to the P. of P., should by sine formula fulfil the following conditions, viz. :—

$$\frac{\text{sine } t}{\text{sine } z} = \frac{\text{sine } a}{\text{sine } p}.$$

Proof

Now $tt' = a_1a_2$. Divide through by $a_1C \cdot tC$.

Then $\frac{tt'}{tC} \cdot \frac{1}{a_1C} = \frac{a_1a_2}{a_1C} \cdot \frac{1}{tC}$.

But a_1C = half chord zz' = sine $z°$, where $z°$ is the distance of zz' from pole of its equator;

and tC = " " pp' = sine $p°$;

and $\frac{a_1a_2}{a_1C}$ = sine $a°$ and $\frac{tt'}{q'C}$ = sine $t°$.

Therefore $\frac{\text{sine } a°}{\text{sine } p°} = \frac{\text{sine } t°}{\text{sine } z°}$ and the above conditions are fulfilled.

Problem VII (Fig. 7: Examples 7 and 8, Sections (*b*) and (*c*))

To project the intersection of the arcs of a Small Circle and of a Great Circle whose planes are not perpendicular to one another, where the plane of the Small Circle is perpendicular to the P. of P., and its arc distant $z°$ from the pole of its equator, and the plane of the Great Circle is inclined at an angle of $t°$ to the P. of P.

Let PT′P′ be the projection of a Great Circle whose plane is inclined at an angle of $t°$ to the P. of P.

Let zz' be the projection of a Small Circle whose plane is perpendicular to the P. of P. and whose arc is distant $z°$ from Z, the pole of its equator. Let the angle PCZ between the common diameter of PT′P′ with the P. of P. and the diameter through the pole of the equator of $zz' = c°$.

Construction (fig. 7)

Let the projection zz' cut PP′ at z_1.

Make QCT $= t°$, and draw TT′ perpendicular to and meeting QQ′ in T′.

Draw T′e parallel to zz', meeting PP′ in e, and join Qe.

" z_1p " " Qe, " the circumference in p.

" pp' " " QQ′, " zz' in X.

Then X is the projection of the intersection of the Great Circle PT′P′ and the Small Circle zz'.

Argument

Through X draw tXt' parallel to PP′, meeting CT in t and QQ′ in t'.

Now, if it be proved that $t\text{C} = \frac{1}{2}$ chord pp', it proves X is the projection of the intersection of the arcs of the Great Circle PT′P′ and of the Small Circle whose projection is pp' (Problem II.).

But X is the projection of the intersection of the Small Circles whose projections are zz' and pp'.

Therefore also will X be the projection of the intersection of the arcs of the Great Circle PT′P′ and of the Small Circle zz'.

Proof

The triangles eQC and z_1pm are similar by construction.

Therefore $$\frac{z_1m}{e\text{C}} = \frac{pm}{\text{QC}} \qquad (1)$$

The triangles eT′C and z_1Xm are also similar by construction.

Therefore $$\frac{z_1m}{e\text{C}} = \frac{\text{X}m}{\text{T}'\text{C}} \text{ and } \text{X}m = t'\text{C} \qquad (2)$$

Hence from (1) and (2) $$\frac{pm}{\text{QC}} = \frac{\text{X}m}{\text{T}'\text{C}} \qquad (3)$$

The triangles TT′C and tt'C are also similar.

Therefore $$\frac{t'\text{C}}{\text{T}'\text{C}} = \frac{t\text{C}}{\text{TC}} \text{ and } t'\text{C} = \text{X}m \qquad (4)$$

Hence from (3) and (4) $$\frac{pm}{\text{QC}} = \frac{t\text{C}}{\text{TC}} \text{ but } \text{QC} = \text{TC}.$$

Therefore $pm = t\text{C}$, or $t\text{C} = \frac{1}{2}pp'$, and X is the required projection.

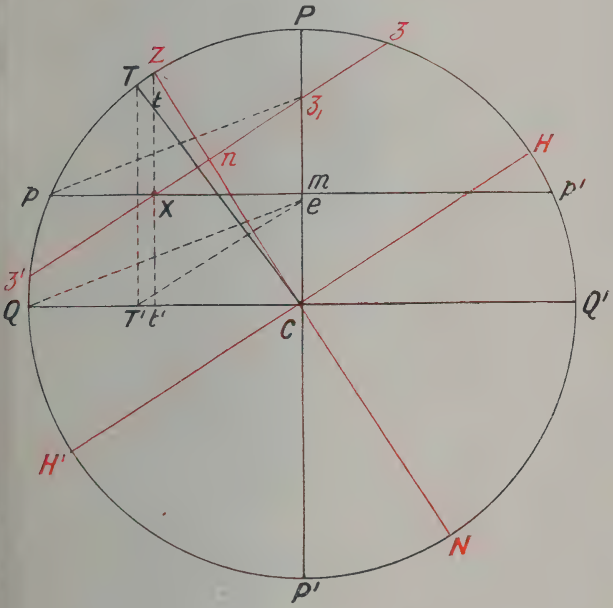
[*To face p.* 182.

FIG. 7.

Problem VII.

Examples 7 and 8. *Sections* (*b*) *and* (*c*).

Projection of intersection of Small and Great Circle planes inclined.



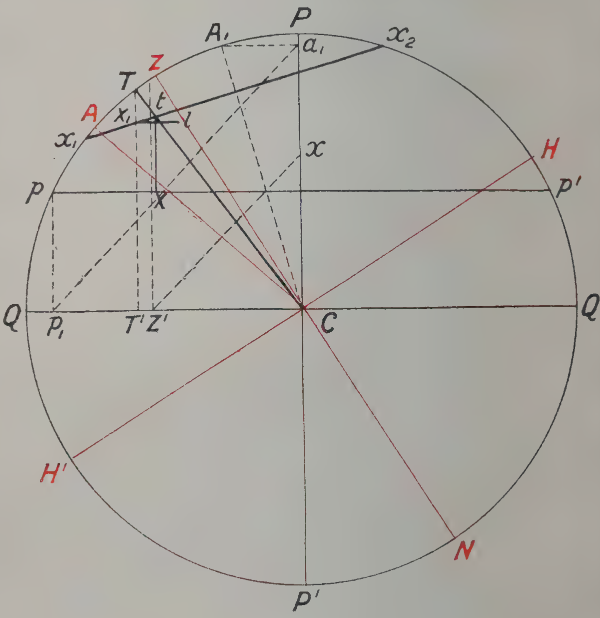
[To face p. 183.

FIG. 8.

Problem VIII.

Examples 10. *Sections* (*b*) *and* (*c*).

Projection of intersection of arcs of two Great Circles.



Problem VIII

(Fig. 8: Examples 10, Sections (*b*) and (*c*))

To project the intersection of the arcs of two Great Circles whose planes are inclined at angles $t°$ and $a°$ respectively to the P. of P., their respective common diameters with the P. of P. including an angle of $c°$.

Let PQP′Q′ be the P. of P., PP′ being its common diameter, with the Great Circle inclined to it at an angle of $t°$.

Let $PCZ = c°$, and rule the diameter ZCN. Then ZN is the common diameter, with the P. of P., of the Great Circle inclined at $a°$ to the P. of P.

Construction

Lay off $QCT = t°$ and $Q'CA_1 = a°$. Draw TT′ and ZZ′ perpendicular to and meeting QQ′ in T′ and Z′.

Draw A_1a_1 perpendicular to and meeting PP′ in a_1.

Along CZ measure $Cl = TT'$, and draw lX_1 perpendicular to and meeting TT′ in X_1.

Through X_1 rule a chord x_1x_2 perpendicular to CA_1. Make Cx along $CP = \frac{1}{2}xx_1$.

Join xZ' and draw a_1p_1 parallel to xZ', meeting QQ′ in p_1.

Draw pp_1 perpendicular to QQ′, meeting the circumference in p, and let $Pp = p°$.

(*N.B.*—In drawing pp' there is ambiguity as to which side of QQ′, but this ambiguity disappears in the practical examples.)

Through p rule a chord pp' parallel to QQ′, and make Ct along $CT = \frac{1}{2}pp'$.

From t draw tX perpendicular to and meeting pp' in X.

Then X is the required projection of the intersection of the arcs of the Great Circles.

Argument

By Problem II., X is the projection of the intersection of the arcs of the Great Circle PT′P′ and pp'.

The Great Circle PXP′ is inclined at $t°$ to the P. of P., and if the Great Circle ZXN is inclined at $a°$ to the P. of P., then the angle $PZX = a°$, and X is the required projection.

Proof

Now PZX is the projection of a spherical triangle in which, by construction, angle ZPX measured by $QCT = t°$, side $PZ = c°$, and side Px projected by $PX = p°$.

And QA_1X_1 is the projection of a spherical triangle in which, by construction, angle A_1QX_1 measured by $PCZ = c°$, side $QA_1 = (180 - a°)$, and side $QX_1 = QT = t°$.

Let the radius of the sphere be unity, then

$$\frac{\text{sine PX}}{\text{sine PZ}} = \frac{\frac{1}{2}pp'}{\text{sine } c°} = \frac{p_1C}{CZ'} = \frac{a_1C}{Cx} = \frac{\text{sine } a°}{\frac{1}{2}x_1x_2} = \frac{\text{sine } a°}{\text{sine } A_1X_1} = \frac{\text{sine } A_1X_1Q}{\text{sine } A_1QX_1} = \frac{\text{sine } A_1X_1Q}{\text{sine } c°}.$$

Hence sine A_1X_1Q = sine PX = sine $p°$ or sine $(180° - p°)$.

Therefore $A_1X_1Q = p°$ or $180° - p°$. Fig. 8 shows A_1X_1Q is over 180° and therefore $180° - p°$).

Now, in the triangle PZX (p. 180 (*b*))

$$\text{cosine } ZX = \text{cosine } c^\circ \text{ cosine } p^\circ + \text{sine } c^\circ \text{ sine } p^\circ \text{ cosine } t^\circ.$$

And in the triangle QA_1X_1 (p. 180 (*c*))

$$\begin{aligned} \text{cosine } QA_1X_1 &= -\text{cosine } c^\circ \text{ cosine } (180^\circ - p^\circ) + \text{sine } c^\circ \text{ sine } p^\circ \text{ cosine } t^\circ \\ &= \text{cosine } c^\circ \text{ cosine } p^\circ + \text{sine } c^\circ \text{ sine } p^\circ \text{ cosine } t^\circ. \end{aligned}$$

Therefore the arc measuring the side ZX = the arc measuring the angle QA_1X_1, and similarly it may be shown that the remaining angle and side of the above triangles are measured by equal arcs or are supplementary.

Fig. 8 shows that QA_1 is under 180° and angle PZX is over 180°.

Therefore $PZX = 180^\circ - QA_1 = a^\circ$, and X is the required projection.

Problem IX (Figs. 1 and 2 and 3 and 4)

To prove that, on a sphere where the plane of a Small Circle is parallel to the plane of a Great Circle, the arcs of these circles intercepted between two Great Circles that are perpendicular to both bear the following relation :—Arc of Small Circle = Arc of Great Circle × Cosine of the normal arc between them.

From Problem I., figs. 1 and 2, it will be seen that the arc of the Great Circle intercepted between the Great Circles PEP′ and PT″P′ is the arc ET″.

The projection of this arc on the P. of P. is T′C.

From Problem II., figs. 3 and 4, it will be seen that the arc of the Small Circle intercepted between the Great Circles PEP′ and PT″P′ is the arc $m'x$.

The projection of this arc on the P. of P. is mx.

Let tX produced meet QQ′ in t', and draw TT′ perpendicular to QQ′.

Then the triangles TT′C and tt'C are similar and $\dfrac{t'C}{T'C} = \dfrac{tC}{TC}$.

But $t'C = Xm$. $\quad \therefore \dfrac{Xm}{T'C} = \dfrac{tC}{TC}$.

Let the radius of the sphere be unity, then

$$TC = 1 \quad \text{and} \quad tC = pm' = \text{cosine } QCp.$$

Therefore $$\frac{Xm}{T'C} = \text{cosine } QCp.$$

From figs. 2 and 4, the triangles T″CT′ and xCX are similar.

Therefore $$\frac{Xm}{T'C} = \frac{xm}{T''C} = \text{cosine } QCp,$$

and arcs are proportional to their radii.

Therefore $$\frac{\text{arc } xm'}{\text{arc } T''E} = \text{cosine } QCp,$$

or Arc of Small Circle = Arc of Great Circle × Cosine of Qp (the arc intercepted).

The Spherical Diagram

The construction of the Spherical Diagram is based on the principles explained in Problems I. and II., and represents the orthographic projection on a Great Circle section of a sphere of Small Circles whose planes are perpendicular to the section of the sphere and parallel to one another, and of Great Circles whose planes are perpendicular to the planes of the Small Circles but inclined to the section of the sphere. The parallel chords of the diagram represent the projections of Small Circles one degree apart, every fifth being omitted for clearness.

The ellipses of the diagram represent the projections of Great Circles whose planes are one degree apart, every fifth being omitted for clearness, these planes being perpendicular to the planes of the Small Circles represented above.

The construction of the diagram is simple, and is as follows.

The circumference of a circle is divided into degrees, or half degrees, or less, each quadrant being graduated from 0° to 90°.

Two adjacent quadrants have a common zero, and are graduated clockwise and anticlockwise from this zero.

The graduations in one quadrant are inscribed, " North Declination and North Latitude."

The graduations in the other quadrant are inscribed, " South Latitude and South Declination."

The common zero of these two quadrants is marked, " Hour Angle and Diff. Long. ZERO."

The two remaining quadrants have a common 90° graduation diametrically opposite the common zero of the first two quadrants.

The graduations in one quadrant are inscribed, " Altitude of North Pole and Zenith Distance, or Distance."

The graduations in the other quadrant are inscribed, " Distance or Zenith Distance and Altitude of South Pole."

The common 90° graduation of these two quadrants is marked " Azimuth ZERO," as referring to the Azimuth graduations on the diameter.

The diameter joining the common Zero and common 90° is called the Equator.

The diameter at right angles to the Equator is called the Axis, and is marked at its extremities, " Zenith NORTH Pole " and " Zenith SOUTH Pole," to show that these points represent either the North or South Pole respectively, or observer's Zenith North or South of the Equator respectively.

The chords representing the Small Circles are ruled parallel to the Equator by joining degree graduations consecutively in adjacent quadrants, every fifth being omitted.

The Ellipses are formed by dividing every chord in the same proportions that the Axis of the diagram is divided by the Small Circle chords. The curves are formed by joining the points thus obtained.

The points where these Ellipses cut the Equator are graduated from 0° to 180° from right to left and *vice versa*, the zeros of these scales being the "Hour Angle and Diff. Long. ZERO" and the "Azimuth ZERO."

If the Parallel and Circle passing through any point on the surface of the sphere be known, the projection of that point on the diagram is given by the intersection of the Chord of the given Parallel and the Ellipses of the given Circle.

The radius of this projected point from the centre can be measured by ruler.

This radius is called the Locus Radius of that point.

Problems are solved on the diagram in two ways:—

(*a*) By measuring the Locus Radius and turning it through a known angle, or by turning it till its extremity lies on another known Parallel or a known Ellipse, when other elements can be determined; or

(*b*) By measuring the chord of a known Parallel and turning this chord with its extremities lying on the circumference of the diagram through a given angle. Then the intersection of this chord with another known Parallel or known Ellipse enables other elements to be determined.

In such manner, by simple measurement with a ruler or with dividers, all Great Circle Sailing and Nautical Astronomy problems can be solved, as explained in Sections (*b*) and (*c*).

In using the diagram, always place it with the observer's pole uppermost, thus:—

In North Latitude the point marked "Zenith NORTH Pole" is uppermost.

In South Latitude the point marked "Zenith SOUTH Pole" is uppermost.

Instead of a ruler a thread may be used, attached to a pin at the centre of the diagram. This enables intersections of Parallels and Ellipses to be more readily seen.

SECTION (b)

Great Circle Sailing

In Great Circle Sailing a ship proceeds from the "Departure Point" to the "Destination Point," following the track of the Great Circle passing through these two places.

The angle at which the Great Circle track meets the intervening meridians continually alters; consequently the "Course" of the vessel must be frequently changed in order that her track, by successive short runs on Rhumb Line Tracks, may closely approximate the Great Circle Track.

(1) Projection of Latitude and Difference of Longitude of Destination (x) (figs. 3 and 4)

The Terrestrial Meridian of a place is that half Great Circle of the Earth's surface from Pole to Pole that passes through the place.

In Great Circle Sailing problems the P. of P. is the plane of the meridian of either :—

(*a*) The Departure Point (this point is denoted by Z);
(*b*) ,, Destination Point (,, ,, ,, x); or
(*c*) ,, Highest Latitude Point (,, ,, ,, V).

Let PQP′Q′ be the P. of P., C its centre and the centre of the Earth, PP′ the axis of the Earth.

Let P be the North Pole, P′ the South Pole, and PQP′Q′ the plane of the meridian of the place.

The Equator is that Great Circle of the Earth whose plane is perpendicular to the planes of the meridians and whose axis is the axis of the Earth.

The diameter QQ′ at right angles to PP′ is therefore the projection of the Equator.

Latitude Parallels are Small Circles whose planes are parallel to the plane of the Equator. Let QCp be the Latitude of a place x.

Then pp', parallel to QQ′, is the projection of the Latitude Parallel on which x is situated.

Latitude is measured North or South from zero at Q to 90° at P or P′.

Longitude Circles are half Great Circles joining the Poles of the Earth whose planes are perpendicular to the plane of the Equator QQ′ and are inclined at angles of $t°$, called the Difference of Longitude, to the plane PQP′—the plane of the meridian of the place.

Difference of Longitude is measured East or West from zero at Q to 180° at Q′.

Let PxP′ be a Longitude Circle through the Destination x. The angle $t°$ between the plane PQP′C and the plane of PxP′ is the Diff. of Long. between any place on the meridian PQP′ and x.

With Latitude and Diff. Long. of x to project the Destination x

Let $p°$ be the Latitude of x, and $t°$ the Difference of Longitude of x from Z.

As in Problem II., lay off angle $QCp = p°$ and rule the Latitude Parallel pp' parallel to QQ'.

Lay off $QCT = t°$ and measure Ct along CT = half the chord pp'.

From t draw tX perpendicular to and meeting pp' in X.

Then X is the projection on the plane of the meridian of Z of the Destination x.

The radius CX is called the Locus Radius of X. The Locus of X is the dotted circle.

(2) Projection of the Distance and Azimuth of Destination (figs. 3*a* and 4*a*)

Let ZHNH′, the P. of P., be the plane of the meridian used as in (1).

Let ZN, however, be that diameter of the Earth through the place Z.

The Horizontal is that Great Circle of the Earth whose plane is perpendicular to ZN. The diameter HH′ at right angles to ZN is the projection of the Horizontal.

Distance Parallels are Small Circles whose planes are parallel to the plane of the Horizontal.

Let ZCz be the distance of a place x from Z.

Then zz' parallel to HH′ is the projection of the Distance Parallel on which x lies.

Distance is measured from zero at Z through 180° or 10,800 miles at N.

Azimuth Circles are half Great Circles joining Z and N whose planes are perpendicular to the plane of the Horizontal and inclined at angles $a°$, called "Azimuths," to the plane ZHNC.

Azimuths are measured clockwise through 360°, from zero at H through 180° at H′.

Going East—Azimuths lie between 0 and 180°.

„ West— „ „ „ 180° and 360°.

Let ZxN be an Azimuth Circle through a place x. The angle $a°$ between the plane ZHNC and the plane ZxN is the Azimuth of x.

With Distance and Azimuth of x to project x

Let $z°$ be the Distance of x, and $a°$ the Azimuth of x.

As in Problem II., lay off angle $ZCz = z°$ and rule Distance Parallel zz' parallel to HH′.

Lay off $HCA = a°$ and measure Ca along CA = half the chord zz'.

From a draw aX perpendicular to and meeting zz' in X.

Then X is the projection on the plane of the meridian of Z of the Destination x.

The radius CX is called the Locus Radius of X. The Locus of X is the dotted circle.

(3) To correlate the Projections of x

With the same place x projected on the same P. of P., the radius CX from the Earth's centre must in both the "Latitude x—D. Long. x" and "Distance x—Azimuth x" projections be equal.

Lay fig. 3*a* on fig. 3 with the centres coincident and the points X also coincident.

Then the angle PCZ between the diameters PP′ and ZN is the Co-latitude of Z.

And PZX is the projection of the Spherical Triangle connecting the Pole, Departure, and Destination Points.

(4) Use of the Spherical Diagram

Mark on the diagram the intersection of the known Lat. Parallel and D. Long. Ellipse of x, or Dist. Parallel and Azimuth Ellipse of x.

The radius from the centre of the diagram to this point is the Locus Radius of X.

Turn the radius CX through the angle of the Co-latitude of Z, using the circumferential graduation.

The extremity of the radius meets the intersection of the required Dist. Parallel and Azimuth Ellipse of x, or Lat. Parallel and D. Long. Ellipse of x.

If the Lat. Z is North, turn clockwise for Distance and Azimuth, anticlockwise for Lat. x and D. Long.

If the Lat. Z is South, turn anticlockwise for Distance and Azimuth, clockwise for Lat. x and D. Long.

If Latitude Z is South, read Azimuths on the Difference of Longitude graduations.

Examples

Ex. 1.—*To find Distance and Azimuth of* x—*Given Latitude and D. Long. of* x *and Latitude Z.*

Ex. 2.—*To find Latitude Z and Azimuth of* x—*Given Latitude and D. Long. of* x *and Distance of* x.

Ex. 3.—*To find Distance of* x *and Latitude Z—Given Latitude and D. Long. of* x *and Azimuth of* x.

Using the Spherical Diagram

In the three above examples the radius CX is at once determined, X being at the intersection of the given Latitude Parallel and D. Long. Ellipse of x.

Measure this radius, and revolve the radius about the centre—*clockwise* if Lat. Z is *North, anticlockwise* if Lat. Z is *South*, as below.

Ex. 1.—Turn the measured radius through the Co-latitude Z, and mark where X then lies. The Parallel and Ellipse through this point are the Distance Parallel and Azimuth Circle respectively of x.

Ex. 2.—Turn the measured radius till its extremity lies on the given Distance Parallel. The angle turned through is the Co-latitude Z. The Ellipse through this point is the Azimuth.

Ex. 3.—Turn the measured radius till its extremity lies on the given Azimuth Ellipse. The angle turned through is the Co-latitude Z. The Parallel through this point is the Distance Parallel.

Note.—Going West, subtract azimuths, read from 360°.

Solutions by Projection

On the plane of the meridian of Z (axes PP′ and QQ′), with the given Latitude and D. Long. of x, project X as in Problem II., figs. 3 and 4.

Ex. 1.—Lay off QCZ=Latitude Z, and rule the diameters ZCN and HH′ at right angles.

Through X rule chord zz' parallel to HH′. Then Zz is the Distance of x.

Through X rule chord Xa parallel to ZN, and let a radius C$a=\frac{1}{2}zz'$ meet Xa in a.

The angle HCa is the Azimuth. Going West, subtract Azimuths, read from 360°.

Ex. 2.—From P lay off PCd=the Distance, and rule chord dd' parallel to QQ′.

About C describe a circle touching dd', and through X rule a chord 33′ touching the circle.

Inspection will show which chord through X touching the circle is the Distance Parallel.

Rule a diameter ZCN perpendicular to zz'.

Then QCZ is the Latitude. The Azimuth is found as in Ex. 1.

Ex. 3.—From Q′C lay off the Azimuth Q′CA$_1=a°$ (fig. 6).

Through t draw ta_1 parallel to QQ′, meeting CA$_1$ in a_1.

Through a_1 rule a chord perpendicular to CA$_1$ and describe a circle about C with radius equal to half this chord.

Through X rule a chord zz' touching the circle.

Inspection will show which chord through X touching the circle is the Distance chord.

Rule a diameter ZCN perpendicular to zz'.

Then PCZ is the Co-latitude Z, and ZCz is the Distance of x.

Ex. 4.—*To find Latitude and D. Long. of* x—*Given Distance and Azimuth of* x *and Latitude Z.*

Ex. 5.—*To find Latitude Z and D. Long. of* x—*Given Distance and Azimuth of* x *and Latitude of* x.

Ex. 6.—*To find Latitude of* x *and Latitude Z—Given Distance and Azimuth of* x *and D. Long. of* x.

Using the Spherical Diagram

In the three above examples the radius CX is at once determined, X being at the intersection of the given Distance Parallel and Azimuth Ellipse of x.

Measure this radius, and revolve the radius about the centre thus: *anticlockwise* if Latitude Z is *North, clockwise* if Latitude Z is *South,* as below.

Ex. 4.—Turn the measured radius through the Co-latitude Z, and mark where X then lies. The Parallel and Ellipse through this point are the Latitude Parallel and D. Long. Circle of x respectively.

Ex. 5.—Turn the measured radius till its extremity lies on the given Latitude x Parallel. The angle turned through is the Co-latitude of Z. The Ellipse through this point is the D. Long.

Ex. 6.—Turn the measured radius till its extremity lies on the given D. Long. Ellipse. The angle turned through is the Co-latitude of Z. The parallel through this point is Latitude x.

Note.—Going West, subtract Azimuths, read from 360°.

Solutions by Projection

On the plane of the meridian of Z (axes ZN and HH′), with the given Distance and Azimuth of x, project X as in Problem II., figs. 3*a* and 4*a*.

Ex. 4.—Lay off HCP=Latitude Z, and rule the diameters PCP′ and QQ′ at right angles.
Through X rule chord pp' parallel to QQ′. Then Qp is the Latitude of x.
Through X rule chord Xt parallel to PP′, and let a radius $Ct=\frac{1}{2}pp'$ meet Xt in t.
The angle QCt is the D. Long. of x.

Ex. 5.—From H lay off Hcd=Latitude x, and rule a chord dd' parallel to HH′.
About C describe a circle touching dd', and through X rule a chord pp' touching this circle.
Inspection will show which chord through X touching the circle is the Latitude x Parallel.
Rule a diameter QCQ′ parallel to pp'.
Then QCZ is the Latitude Z. The D. Long. is found as in Ex. 4.

Ex. 6.—From H′C lay off the D. Long. $H'CT_1=t°$ (fig. 6).
Through a draw t_1a parallel to HH′, meeting CT_1 in t_1.
Through t_1 rule a chord perpendicular to CT_1, and describe a circle about C with radius equal to half this chord.
Through X rule a chord pp' touching the circle.
Inspection will show which chord through X touching the circle is the Latitude x chord.
Rule a diameter QCQ′ parallel to pp'.
Then QCZ is the Latitude Z and QCp is the Latitude x.

Ex. 7.—*To find the Distance and D. Long. of* x—*Given Latitude Z, Latitude and Azimuth of* x.

Ex. 8.—*To find the Latitude and Azimuth of* x—*Given Latitude Z, Distance and D. Long. of* x.

Ex. 9.—*To find the D. Long. and Azimuth of* x—*Given Latitude Z, Latitude and Distance of* x.

Using the Spherical Diagram

In these examples the *Latitude* Z is given, also Latitude or Distance Parallel of x, or both.

Measure the chord of the given Parallel, and turn this chord through the angle of the Co-latitude with its extremities lying on the circumference of the diagram.

Thus, in N. Latitude, turn Latitude x chords *clockwise*, Distance chords *anticlockwise;* in S. Latitude, turn Latitude x chords *anticlockwise*, Distance chords *clockwise*.

Ex. 7.—(*a*) Measure given Lat. x chord and turn it as above.

The Parallel through the intersection of this chord with the given Azimuth Ellipse is the Distance Parallel.

(*b*) Measure this Distance x chord and turn it as above.

The Ellipse through the intersection of this chord with the given Latitude x Parallel is the D. Long. Circle.

Ex. 8.—(*a*) Measure given Dist. x chord and turn it as above.

The Parallel through the intersection of this chord with the given D. Long. Ellipse is the Latitude x Parallel.

(*b*) Measure this Latitude x chord and turn it as above.

The Ellipse through the intersection of this chord with the given Distance x Parallel is the Azimuth Circle.

Ex. 9.—(*a*) Measure given Lat. x chord and turn it as above.

The Ellipse through the intersection of this chord with the given Distance x Parallel is the Azimuth Circle.

(*b*) Measure given Distance x chord and turn it as above.

The Ellipse through the intersection of this chord with the given Latitude x Parallel is the D. Long. Circle.

N.B.—Going West, subtract Azimuths, read from 360°.

Solutions by Projection

On the plane of Meridian of Z (axes PP′ and QQ′) lay off QCZ=Latitude Z, and rule axes ZN and HH′.

Ex. 7 (fig. 6).—Rule the Latitude x Parallel pp_1p' meeting ZN in p_1, and lay off HCA=Azimuth x.

Draw AA′ perpendicular to and meeting HH′ in A′. Draw A′e parallel to QQ′, meeting ZN in e.

Join eH′ and draw p_1z' parallel to H′e, meeting the circumference nearer H′ at z'.

Then Zz' is the Distance of x. The D. Long. is then found as in Ex. 4.

Ex. 8 (fig. 6).—Rule the Distance x Parallel $z'z_1z$ meeting PP′ in z_1, and lay off QCT=D. Long. of x.

Draw TT′ perpendicular to and meeting QQ′ in T′. Draw T′e parallel to HH′ meeting PP′ in e.

Join eQ and draw z_1p parallel to Qe, meeting the circumference nearer Q at p.

Then Qp is the Latitude x. The Azimuth is then found as in Ex. 1.

Ex. 9 (fig. 5).—Rule the Latitude x Parallel pp' and Distance x Parallel zz' intersecting at X. Thus the radius CX is found.

The D. Long. x is found as in Ex. 4. The Azimuth is found as in Ex. 1.

Ex. 10.—*To find the Latitude and Distance of* x—*Given Latitude Z, D. Long. and Azimuth of* x. *See Problem VIII. The Spherical Diagram is adapted for the solution of this example, thus :—*

Adaptation of Spherical Diagram

(*a*) **To find Distance of** x.—Use Co-latitude Z as Azimuth; D. Long. x as Distance of x.

N.B.—If D. Long. is over 90°, use its supplement, *i.e.* (180° – D. Long).

Measure the radius to the intersection of above Ellipse and Parallel, and turn this radius through the angle of the Azimuth, thus :—

If Lat. Z is N., turn clockwise; if Lat. Z is S., turn anticlockwise.

The Ellipse met by the extremity of the radius, read as Azimuth, is the Distance of x.

N.B.—Note the Parallel met by the extremity of the radius.

(*b*) **To find the Latitude of** x.—Use Co-latitude z as D. Long.; Azimuth as Distance of x.

N.B.—If Azimuth is over 90°, use its supplement, *i.e.* (180° – Azimuth).

Measure the radius to the intersection of above Ellipse and Parallel, and turn this radius through the angle of the D. Long., thus :—

If Lat. Z is N., turn clockwise; if Lat. Z is S., turn anticlockwise.

The Ellipse met by the extremity of the radius, read as Azimuth, is the Co-latitude of x.

Note.—In any one example the Parallels met in (*a*) and (*b*) above are the chords measuring double the Azimuth of Departure Z from Destination x, and are therefore the same in both. This checks correct work.

Solution by Construction

The construction is the same as Problem VIII. An alternative method is here given.

N.B.—Always lay off D. Long and Azimuth oppositely, *i.e.* one clockwise and the other anticlockwise.

(*a*) **To find Distance of** x.—On the axes PP′ and QQ′, at right angles to one another—

Lay off QCT = D. Long., and rule TT′ perpendicular to and meeting QQ′ in T′.

,, QCZ = Latitude Z, and make Cl along CZ = TT′.

Draw $l X_1$ perpendicular to and meeting TT′ in X_1.

Lay off $Q'CA_1$ = Azimuth, and through X_1 rule chord x_1x_2 perpendicular to CA_1.

Let a radius $Ce = \frac{1}{2}x_1x_2$ meet chord through X_1 parallel to CA_1 in e, and the circumference in z_1.

Then A_1z_1 is the Distance of x.

(*b*) **To find Latitude of** x.—On the axes ZN and HH′, at right angles to one another—

Lay off HCA = Azimuth of x, and rule AA′ perpendicular to and meeting HH′ in A′.

,, HCP = Latitude of Z, and make Cl along CP = AA′.

Draw $l X_1$ perpendicular to and meeting AA′ in X_1.

Lay off $H'CT_1$ = D. Long. of x, and through X_1 rule chord x_1x_2 perpendicular to CT_1.

Let a radius $Ce = \frac{1}{2}xx'$ meet chord through X_1 parallel to CT_1 in e, and the circumference in p_1.

Then T_1p_1 is the Latitude of x.

Note (1).—In any one example the chords x_1x_2 in above constructions (*a*) and (*b*) are chords of double the Azimuth of Departure Z from Destination x, and are therefore equal in both. This checks correct work.

Note (2).—When Distance x is found, Latitude x can be found as in Ex. 9, and *vice versa*.

Examples involving the Vertex

The Vertex of the Great Circle joining two places is that point where this Great Circle cuts a meridian at right angles and most closely approaches the Pole nearer the two places.

The Vertex may be "within the Great Circle Track," *i.e.* on the Great Circle Track joining the two places, or it may be "without the Great Circle Track," *i.e.* on the continuation of the Great Circle beyond the Track joining the two places.

At the Vertex the Azimuths of the Departure and Destination Points are due East or West.

Examples involving the Vertex are important in being the only practical means of employing Great Circle Sailing, for after the Latitude of the Vertex has been found, Latitudes and Longitudes of points on the Great Circle Track can be determined, and the Track can by these means be plotted on a Mercator's Chart.

Further, when the Latitudes and Longitudes of points on the Great Circle Track have been ascertained, the Course to steer by Compass and the Distance to run on the Rhumb Line Track from point to point are easily measured on the Mercator's Chart or determined by the formulæ of the Sailings (Part I.), and in this manner the Great Circle Track is closely approximated.

Ex. 11.—*To find the Latitude of the Vertex—Given Latitude Z, Latitude* x, *and Diff. of Long.*

Using the Spherical Diagram

Find the Distance and Azimuth of x as in Ex. 1.

Follow the Azimuth Ellipse to its intersection with the Latitude Z Parallel, and measure the radius of this point.

Turn this radius till it lies on the axis joining the Poles of the diagram.

The Parallel met by the extremity of the radius is the Latitude of the Vertex.

Solution by Projection (fig. 9)

On the Meridian of Z (axes PP′ and QQ′) lay off QCZ=Latitude Z, and rule axes ZN and HH′.

With Latitude and D. Long. of x project X and find the Distance and Azimuth of x as in Ex. 1.

Let CA be the Azimuth radius. Draw Af perpendicular to and meeting ZN in f.

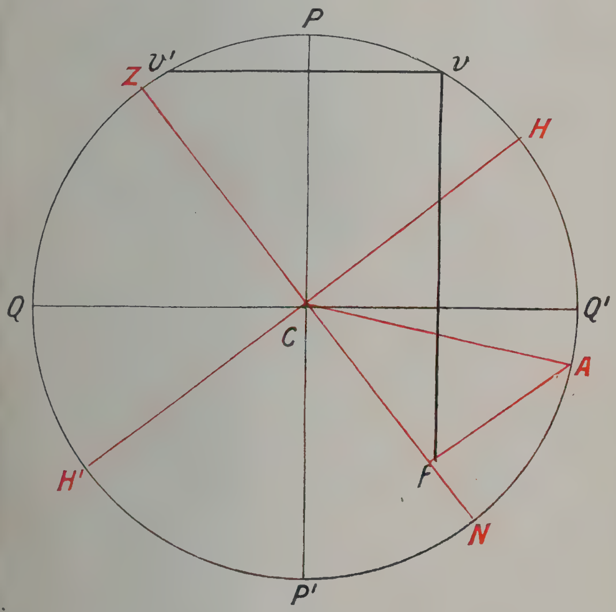
Draw fv parallel to PP′, meeting the circumference nearer the Pole of Z and x at v.

A chord through v parallel to QQ′ is the Latitude of the Vertex.

FIG. 9.

Example 11. *Section* (*b*).

The Vertex of a Great Circle joining two places.



Examples

Ex. 12.—*To find Dist. and D. Long. of Vertex from Z and* x—*Given Latitudes of Z and* x *and Latitude of Vertex.*

Ex. 13.—*To find Latitudes and Longitudes of points on the track —Given Latitudes of Z and* x *and Latitude of Vertex.*

Ex. 14.—*To find Dists. and D. Longs. of points on the track—Given Latitudes of Z and* x *and Latitude of Vertex.*

Using the Spherical Diagram

In these three Examples the Spherical Diagram represents the plane of the Meridian of the Vertex.

A ruler graduated with divisions equal to the divisions on the radius to either Pole of the diagram, as cut off by the Parallels, will enable Latitudes or Distances of points on the Track to be directly read off.

Ex. 12.—Lay a ruler on radius to graduation on Latitude Scale =Latitude of Vertex.

The points where Latitude Parallels of Z and x cut ruler edge are the projections of Z and x.

The Ellipses through these points are the D. Long. Circles of Z and x from the Vertex.

Turn the radius to Z or to x to lie on the axis of the diagram to Pole.

The Parallels through these points are the Distances of Z and x from the Vertex.

Ex. 13.—Lay a ruler on radius to graduation on Latitude Scale = Latitude of Vertex.

The point where any Latitude Parallel cuts ruler edge is the projection of where Track cuts that Latitude.

Hence the Ellipse through this point is the D. Long. Circle from Vertex of that Latitude.

Similarly, the point where any Ellipse cuts ruler edge is the projection of where the Track cuts this D. Long. Circle.

Hence the Parallel through this point is the Latitude of this D. Long. from the Vertex.

Ex. 14.—Lay a ruler on radius to graduation on Latitude Scale = Latitude of Vertex.

Measure, along axis of diagram, radius to required Dist. Parallel. Turn this radius to lie on ruler edge.

The Parallel through this point is the Latitude of this Distance from Vertex.

The Ellipse through this point is the D. Long. of this Distance from the Vertex.

Note (1).—All the D. Longs. above refer to D. Long. from Vertex and not from Z or x.

Note (2).—If Vertex is " within " Track—D. Long. between Z and x = Sum of D. Longs. of Z and x from Vertex.

If Vertex is " without " Track—D. Long. between Z and x = Difference of D. Longs. of Z and x from Vertex.

Solutions by Projection

On the plane of Meridian of Vertex (axes PP′ and QQ′) lay off QCV = Latitude of Vertex, and rule diameter VCV′.

Ex. 12 (fig. 10).—Let VV′ cut the Lat. Parallels of Z and *x* at Z and X. These points are the projections of Z and *x*.

Chords through Z and X perpendicular to VV′ are the Distance Parallels of Z and *x* from the Vertex.

The D. Longs. of Z and *x* from the Vertex are found as in Ex. 4.

Ex. 13 (fig. 10).—Let *ll′* be any Latitude Parallel parallel to QQ′ cutting VV′ at L. Then L is the projection of the point where the Track cuts this Latitude.

The D. Long. of L from V is found as in Ex. 4.

Ex. 14 (fig. 10).—Let *dd′* be any Distance Chord perpendicular to VV′ and cutting it at D.

Then D is the projection of a point on the Track V*d* minutes or miles from the Vertex.

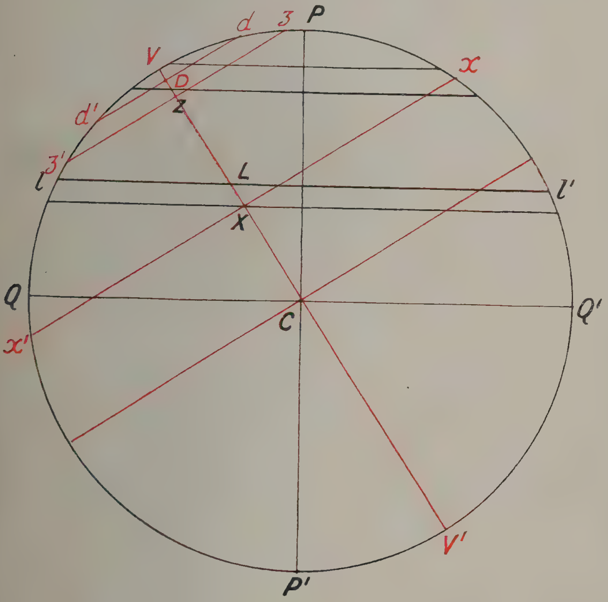
Through D rule a chord parallel to QQ′. This chord is the Latitude Parallel of D.

The D. Long. of D from V is found as in Ex. 4.

FIG. 10.

Examples 12 *to* 18. *Section* (*b*).

Examples involving the Vertex and Composite Sailing.



Composite Sailing

In Composite Sailing a ship proceeds from a Departure Point to a certain "Highest Latitude," on a Great Circle Track which touches the Highest Latitude Parallel at a point V_1.

The ship then proceeds East or West along this Highest Latitude Parallel to a point V_2. At the point V_2 the ship then proceeds on a Great Circle Track which touches the Highest Latitude Parallel to the Destination Point x she is bound for.

At V_1 and V_2, where the Great Circle Tracks touch the Highest Latitude Parallel, the Great Circle Tracks cut the meridians of V_1 and V_2 respectively at right angles, and the Azimuths of Z from V_1 or X from V_2 are due East or West (90° or 270°).

V_1 and V_2 are the Vertices of the Great Circle Tracks ZV_1 and V_2x respectively, and the Highest Latitude Parallel is the Latitude of the Vertex of both Great Circle Tracks.

Composite Sailing corresponds to a Great Circle Track opened at the Vertex by the distance run on the Highest Latitude Parallel.

Composite Sailing is the form of Great Circle Sailing most commonly met with, and as the Lat. of Vertex or Highest Lat. Parallel of the Track is known, the solution of examples is quick and simple.

In these examples the P. of P. is the plane of both the vertices V_1 and V_2 laid one on the other, as if the section of the sphere containing the run on the Latitude Parallel were omitted.

Examples

Ex. 15.—*To find Distance and D. Long. of Z and* x *from Highest Lat.—Given Lats. Z and* x *and D. Long. and Highest Latitude.*

Ex. 16.—*To find Distance to run on Highest Lat. Parallel—Given Lats. Z and* x *and D. Long. and Highest Latitude.*

Ex. 17.—*To find Lats. and Longs. of points on Great Circles—Given Lats. Z and* x *and D. Long. and Highest Latitude.*

Ex. 18.—*To find Dists. and D. Longs. of points on Great Circles—Given Lats. Z and* x *and D. Long. and Highest Latitude.*

Using the Spherical Diagram

Ex. 15.—Lay a ruler on radius to graduation on Latitude Scale = Latitude of Vertex. Mark where Lat. Parallels of Z and x cut ruler edge.

The Ellipses through these points are the D. Longs. of Z and x respectively from Highest Lat. Parallel.

Turn the radius to Z or to x, to lie on the axis of the diagram.

The Parallels through these points are the Distances of Z and x respectively from Highest Lat. Parallel.

Ex. 16.—Add the D. Longs. of Z and x from Highest Lat., and subtract sum from D. Long. between Z and x. The remainder is the D. Long. to make good on the Highest Lat. Parallel, and the Distance can be found by:

$$\text{Distance} = \text{D. Long.} \times \text{Cosine Highest Latitude.}$$

Ex. 17 and 18 are the same as Ex. 13 and 14, substituting Highest Latitude for Lat. of Vertex.

Solutions by Projection

The projections of Ex. 15, 17, and 18 are the same as Ex. 12, 13, and 14, substituting Highest Latitude for Latitude of Vertex.

SECTION (c)

Nautical Astronomy

The following examples show how Azimuths may be determined with all the accuracy needful in Ocean Navigation, and how Planets and Stars may be located. The only books therefore necessary for working sights are Logarithmic Tables and the current Nautical Almanac.

(1) Projection of Declination and Hour Angle of a Heavenly Body x (figs. 3 and 4)

The Celestial Meridian of an observer is that half Great Circle of the Celestial Sphere from Pole to Pole that passes through the observer's Zenith.

In Nautical Astronomy problems, the P. of P. is the Great Circle plane of the Celestial Sphere in which the observer's Celestial Meridian lies.

Let PQP′Q′ be the P. of P., C its centre and the centre of the Earth, PP′ the axis of the Celestial Sphere.

Let P be the N., and P′ the S. Celestial Poles, and PQP′ the plane of the observer's Meridian.

The Equinoctial is that Great Circle of the Celestial Sphere whose plane is perpendicular to the planes of the Meridians, and whose axis is the axis of the Celestial Sphere. The diameter QQ′ at right angles to PP′ is therefore the projection of the Equinoctial.

Declination Parallels are Small Circles whose planes are parallel to the plane of the Equinoctial.

Let Q*C*p be the Declination of a heavenly body x.

Then pp' parallel to QQ′ is the projection of the Declination Parallel on which x is situated.

Declination is measured North or South from zero at Q to 90° at P or P′.

Hour Circles are half Great Circles joining the Celestial Poles whose planes are perpendicular to the plane of the Equinoctial QQ′, and are inclined at angles of $t°$, called Hour Angles, to the plane PQP′—the plane of the observer's Meridian.

Hour Angles are measured clockwise through 360° from zero at Q, through 180° at Q′.

Before noon, Hour Angles increase from 12 hours or 180° at Q′ to 24 hours or 360° at Q.

After noon, Hour Angles increase from 0 hours or 0° at Q to 12 hours or 180° at Q′.

Let PxP′ be an Hour Circle through a heavenly body x. The angle $t°$ between the plane PQP′C and the plane of PxP′ is the Hour Angle of x (measured clockwise).

With Declination and Hour Angle of x to project a body x

Let $p°$ be the Declination of x, and $t°$ the Hour Angle of x.

As in Problem II., lay off angle $QCp = p°$, and rule Declination Parallel pp' parallel to QQ'.

Lay off $QCT = t°$, and measure Ct along CT = half the chord pp'.

From t draw tX perpendicular to and meeting pp' in X.

Then X is the projection on the plane of the observer's Meridian of a heavenly body x.

The radius CX is called the Locus Radius of X. The Locus of X is the dotted circle.

(2) Projection of the Zenith Distance and Azimuth of a Heavenly Body x (figs. 3*a* and 4*a*)

Let ZHNH′ the P. of P. be the plane of the observer's Meridian, as in (1).

Let ZN, however, be that diameter of the Celestial Sphere through the Zenith and Nadir of the observer, Z being the observer's Zenith and N his Nadir.

The Horizon is that Great Circle of the Celestial Sphere whose plane is perpendicular to ZN. The diameter HH′ at right angles to ZN is the projection of the Horizon.

Zenith Distance Parallels are Small Circles whose planes are parallel to the plane of the Horizon.

Let ZCz be the Zenith Distance of a heavenly body x from the Zenith Z.

Then zz' parallel to HH′ is the projection of the Zenith Distance Parallel on which x is situated.

Zenith Distance is measured on the circumference from zero at Z to 90° at H or H′.

The Zenith Distance of the Twilight Parallel is 108° from Z.

Azimuth Circles are half Great Circles joining Z and N whose planes are perpendicular to the plane of the Horizon and inclined at angles ($a°$), called Azimuths, to the plane ZHNC.

Azimuths are measured clockwise through 360°, from zero at H through 180° at H′.

Before noon, Azimuths lie between 0° and 180°.

After noon, Azimuths lie between 180° and 360°.

Let ZxN be an Azimuth Circle through a heavenly body x. The angle $a°$ between the plane ZHNC and the plane of ZxN is the Azimuth of x.

With Zenith Distance and Azimuth of x to project x

Let $z°$ be the Zenith Distance of x, and $a°$ the Azimuth of x.

As in Problem II., lay off angle $ZCz = z°$, and rule Zenith Dist. Parallel zz' parallel to HH′.

Lay off HCA $= a^\circ$, and measure Ca along CA = half the chord zz'.

From a draw aX perpendicular to and meeting zz' in X.

Then X is the projection on the plane of the observer's Meridian of the heavenly body x.

The radius CX is called the Locus Radius of X. The Locus of X is the dotted circle.

(3) To Correlate the Projections of x

With the same body x projected on the same P. of P. the radius CX from the Earth's centre must in both the "Declination-Hour Angle" and "Zenith Distance-Azimuth" projections be equal.

Lay fig. 3a on fig. 3 with the centres coincident and the points X also coincident. Then the angle PCZ between the diameters PP′ and ZN is the Co-latitude of the observer. And PZX is the projection of the Spherical Triangle connecting the Pole, Zenith, and heavenly body.

(4) Use of the Spherical Diagram

Mark on the diagram the intersection of the known Decl. Parallel and Hour Circle, or Zenith Dist. Parallel and Azimuth Circle.

The radius from the centre of the diagram to this point is the Locus Radius of X.

Turn the radius CX through the angle of the Co-latitude, using the circumferential graduation.

The extremity of the radius meets the intersection of the required Zenith Dist. Parallel and Azimuth Ellipse, or Decl. Parallel and Hour Ellipse.

If the Lat. is N., turn clockwise for Zenith Dist. and Azimuth, anticlockwise for Decl. and Hour Angle.

If the Lat. is S., turn anticlockwise for Zenith Dist. and Azimuth, clockwise for Decl. and Hour Angle.

In South Latitude read Azimuths on the Hour Angle graduations.

Examples

Ex. 1.—*To find Zenith Distance and Azimuth—Given Declination, Hour Angle, and Latitude.*

Ex. 2.—*To find Latitude and Azimuth—Given Declination, Hour Angle, and Zenith Distance.*

Ex. 3.—*To find Zenith Distance and Latitude—Given Declination, Hour Angle, and Azimuth.*

Using the Spherical Diagram

In the three above examples the radius CX is at once determined, X being at the intersection of the given Declination Parallel and Hour Angle Ellipse.

Measure this radius and revolve the radius about the centre—*clockwise* in *North* Lat., *anticlockwise* in *South* Lat., as below.

Ex. 1.—Turn measured radius CX through the Co-latitude, and mark where X then lies. The Parallel and Ellipse through this point are the Zen. Dist. Parallel and Azimuth Circle respectively.

Ex. 2.—Turn the measured radius till its extremity lies on the given Zenith Distance Parallel. The angle turned through is the Co-latitude. The Ellipse through this point is the Azimuth.

Ex. 3.—Turn the measured radius till its extremity lies on the given Azimuth Ellipse. The angle turned through is the Co-latitude. The Parallel through this point is the Zenith Distance Parallel.

Note.—If body is rising, subtract Hour Angles, read from 360°.
„ „ setting, „ Azimuths „ „ 360°.

Finding Azimuths (Ex. 1 and 2) when near the Meridian

Near the Meridian Hour Ellipses are close and accuracy is difficult.

Azimuths may be determined by another method as accurately as when body is nearly E. or W. In this method the P. of P. is the plane of the 6 o'clock Hour Circle, *i.e.* that Hour Circle perpendicular to the Meridian.

The Axis PP′ then becomes the Meridian of the place.

Using the Spherical Diagram

Add 90° to Hour Angle, and with this and given Declination project X.

Lay a ruler edge on X parallel to axis of diagram.

Let a radius from the centre, equal to half the chord of the Zenith Distance Parallel, meet the ruler edge at *a*.

This radius makes an angle with the axis equal to the angle that the Azimuth Circle through the body makes with the Meridian.

This angle can be measured directly on the circumferential graduation.

N.B.—The Zenith Distance, if not given, can be found as in Ex. 1, or near the Meridian Zenith Distance is nearly = (Lat. ± Declination).

Solution of Ex. 1, 2, and 3 by Projection

This is the same as Ex. 1, 2, and 3. Section (*b*) (page 190), substituting—

Declination for Lat. of *x*.	Zenith Distance for Distance of *x*.
Hour Angle „ D. Long. of *x*.	Azimuth „ Azimuth of *x*.
Latitude „ Lat. Z	

Ex. 4.—*To find Declination and Hour Angle—Given Zenith Distance, Azimuth, and Latitude.*

Ex. 5.—*To find Latitude and Hour Angle—Given Zenith Distance, Azimuth, and Declination.*

Ex. 6.—*To find Declination and Latitude—Given Zenith Distance, Azimuth, and Hour Angle.*

Using the Spherical Diagram

In the three above examples the radius CX is at once determined, X being at the intersection of the given Zenith Distance Parallel and Azimuth Ellipse.

Measure this radius and revolve the radius about the centre—*anticlockwise* in *North* Lat., *clockwise* in *South* Lat., as below.

Ex. 4.—Turn the measured radius through the Co-latitude Z, and mark where X then lies. The Parallel and Ellipse through this point are the Decl. Parallel and Hour Angle Circle respectively.

Ex. 5.—Turn the measured radius till its extremity lies on the given Declination Parallel. The angle turned through is the Co-latitude. The Ellipse through this point is the Hour Angle.

Ex. 6.—Turn the measured radius till its extremity lies on the given Hour Angle Ellipse. The angle turned through is the Co-latitude. The Parallel through this point is the Declination.

Note.—If body is rising, subtract Hour Angles, read from 360°.
„ „ setting, „ Azimuths, „ „ 360°.

Finding Hour Angles (Ex. 4 and 5) when near the Meridian

Near the Meridian Azimuth Ellipses are close and accuracy is difficult.

Hour Angles may be determined by another method as accurately as when body is nearly E. or W. In this method the P. of P. is the plane of the Prime Vertical, *i.e.* that Azimuth Circle perpendicular to the Meridian.

The Axis PP′ then becomes the Meridian of the place.

Using the Spherical Diagram

Add 90° to Azimuth, and with this and given Zen. Dist. project X.

Lay a ruler edge on X parallel to axis of diagram.

Let a radius from the centre, equal to half the chord of the Declination Parallel, meet ruler edge in *t*.

This radius makes an angle with the axis equal to the angle that the Hour Circle through the body makes with the Meridian.

This angle can be measured directly on the circumferential graduation.

N.B.—The Declination, if not given, can be found as in Ex. 4, or near the Meridian Declination is nearly = (Lat. $\sim$ Zenith Distance).

Solution of Ex. 4, 5, and 6 by Projection

This is the same as Ex. 1, 2, and 3. Section (*b*) (page 191), substituting—

Declination for Lat. of *x*.	Zenith Distance for Distance of *x*.
Hour Angle „ D. Long. of *x*.	Azimuth „ Azimuth of *x*.
Latitude „ Lat. Z.	

Ex. 7.—*To find Zenith Distance and Hour Angle—Given Latitude, Declination, and Azimuth.*

Ex. 8.—*To find Declination and Azimuth—Given Latitude, Zenith Distance, and Hour Angle.*

Ex. 9.—*To find Hour Angle and Azimuth—Given Latitude, Declination, and Zenith Distance.*

Using the Spherical Diagram

In these examples the *Latitude* is given, also the Declination or Zenith Distance Parallel, or both.

Measure the chord of the given Parallel, and turn this chord through the angle of the Co-latitude with its extremities lying on the circumference of the diagram.

Thus, in N. Latitude, turn Declination chords *clockwise*, Zenith Distance chords *anticlockwise* ; in S. Latitude, turn Declination chords *anticlockwise*, Zenith Distance chords *clockwise*.

Ex. 7.—(*a*) Measure given Declination chord and turn it as above.

The Parallel through the intersection of this chord with the given Azimuth Ellipse is the Zenith Distance Parallel.

(*b*) Measure this Zenith Distance chord and turn it as above.

The Ellipse through the intersection of this chord with the given Declination Parallel is the Hour Circle.

Ex. 8.—(*a*) Measure given Zen. Dist. chord and turn it as above.

The Parallel through the intersection of this chord with the given Hour Angle Ellipse is the Declination Parallel.

(*b*) Measure this Declination chord and turn it as above.

The Ellipse through the intersection of this chord with the given Zenith Distance Parallel is the Azimuth Circle.

Ex. 9.—(*a*) Measure given Declination chord and turn it as above.

The Ellipse through the intersection of this chord with the Zenith Distance Parallel is the Azimuth Circle.

(*b*) Measure given Zenith Distance chord and turn it as above.

The Ellipse through the intersection of this chord with the Declination Parallel is the Hour Circle.

N.B.—If body is rising, subtract Hour Angles read from 360°. If body is setting, subtract Azimuths read from 360°.

Solution by Projection

This is exactly similar to Solution by Projection of Ex. 7, 8, and 9, Section (*b*), Great Circle Sailing (page 192), substituting—

Declination	for Lat. of x.	Zenith Distance	for Distance of x.
Hour Angle	,, D. Long. of x.	Azimuth	,, Azimuth of x.
Latitude	,, Lat. Z.		

Ex. 10.—*To find Declination and Zenith Distance—Given Latitude, Hour Angle, and Azimuth. See Problem VIII. The Spherical Diagram is adapted for the solution of this example, thus* :—

Adaptation of Spherical Diagram

(*a*) **To find Zenith Distance.**—Use Co-latitude as Azimuth—Hour Angle as Zenith Distance.

N.B.—If Hour Angle is over 90°, use its supplement, *i.e.* (180° − Hour Angle).

Measure the radius to the intersection of above Ellipse and Parallel, and turn this radius through the angle of the Azimuth, thus :—

If Lat. is N., turn clockwise; if Lat. is S., turn anticlockwise.

The Ellipse met by the extremity of the radius, read as Azimuth, is the Zenith Distance.

N.B.—Note the Parallel met by the extremity of the radius.

(*b*) **To find Declination.**—Use Co-latitude as Hour Angle—Azimuth as Zenith Distance.

N.B.—If Azimuth is over 90°, use its supplement, *i.e.* (180° — Azimuth).

Measure the radius to the intersection of above Ellipse and Parallel, and turn this radius through the angle of the Hour Angle, thus :—

If Lat. is N., turn clockwise. If Lat. is S., turn anticlockwise.

The Ellipse met by the extremity of the radius, read as Azimuth, is the Polar Distance.

Note.—In any one example the Parallels met in (*a*) and (*b*) above are the chords measuring double the angle between the planes of the Hour and Azimuth Circles, and are therefore the same in both. This checks correct work.

Solution by Construction

This is exactly similar to Solution by Construction of Ex. 10, Section (*b*), Great Circle Sailing (page 193), substituting—

Declination	for Lat. of x.	Zenith Distance	for Distance of x.
Hour Angle	,, D. Long. of x.	Azimuth	,, Azimuth of x.
Latitude	,, Lat. Z.		

Special Cases of Preceding Examples

Ex. 11.—*To find Hour Angle and Azimuth of a body Rising or Setting—Given Latitude and Declination.*

Ex. 12.—*To find Zenith Distance and Azimuth of a body, Hour Angle 6 or 18 hours—Given Latitude and Declination.*

Ex. 13.—*To find Zenith Distance and Hour Angle of a body, Azimuth 90° or 270°—Given Latitude and Declination.*

Using the Spherical Diagram

In the three above examples the radius CX is determined from X, being at the intersection of the given Declination Parallel and the Hour Angle Ellipse which is found or given.

Measure this radius, and revolve the radius about the centre, thus—clockwise in N. Latitude, anticlockwise in S. Latitude, as below.

Ex. 11.—Lay a ruler on radius of diagram to given Latitude on "Altitude of Pole" Scale. Mark where Decl. Parallel meets ruler. The radius to this point is CX.

The Ellipse through this point is the Hour Circle at Rising and Setting.

Turn the radius CX through the angle of the Co-latitude as above, *i.e.* to lie on the graduated diameter. The Ellipse through extremity of CX is the Azimuth Circle at Rising and Setting.

Ex. 12.—Lay a ruler on radius of diagram to observer's Pole, either North or South. Mark where Decl. Parallel meets ruler. The radius to this point is CX.

Turn the radius CX through angle of Co-latitude, as above, and mark where extremity of CX rests. The Parallel and Ellipse through this point are the Zenith Dist. Parallel and Azimuth Circle.

Ex. 13.—Lay a ruler on radius of diagram to given Latitude on "Latitude" Scale. Mark where Decl. Parallel meets ruler. The radius to this point is CX.

The Ellipse through this point is the Hour Circle when body bears 90° or 270°.

Turn the radius CX through angle of Co-latitude, as above, *i.e.* to lie on radius to Pole of diagram. The Parallel through extremity of CX is the Zenith Distance.

Note.—In all above, if body is rising, subtract Hour Angles, read from 360°.
" " " setting " Azimuths, " " 360°.

Solutions by Projection

On the plane of observer's Meridian (axes PP′ and QQ′) lay off QCZ = Latitude, and rule axes ZN and HH′.

Lay off QCp = the Declination, and rule pp' parallel to QQ′.

Ex. 11.—Let pp' cut HH′ in X. Then X is the projection of the body at Rising or Setting.
Through X rule a chord AA′ parallel to ZN.
Then HCA is the Azimuth. The Hour Angle is found as in Ex. 4.

Ex. 12.—Let pp' cut PP′ in X. Then X is the projection of the body when Hour Angle is 6 or 18 hours.
Through X rule a chord zz' parallel to HH′.
Then zz' is the Zenith Distance Parallel. The Azimuth is found as in Ex. 1.

Ex. 13.—Let pp' cut ZN in X. Then X is the projection of the body when Azimuth is 90° or 270°.
Through X rule a chord zz' parallel to HH′.
Then zz' is the Zenith Distance Parallel. The Hour Angle is found as in Ex. 4.

Ex. 14.—*To find the Sun's Hour Angle when on Twilight Parallel of* 108°—*Given Latitude and Declination. Twilight commences when the Sun is* 18° *below the Horizon,* i.e. *when the Sun's Zenith Distance is* 108°.

Using the Spherical Diagram

Measure chord of Zenith Distance Parallel of 108°, and turn this chord through the angle of the Co-latitude with its extremities lying on the circumference of the diagram.
Thus, in N. Latitude turn anticlockwise, in S. Latitude turn clockwise.
The Ellipse through the intersection of the chord and the Declination Parallel is the Hour Circle.
For Hour Circles of commencement of Morning Twilight subtract Hour Angle read from 360°.

Solution by Projection

On the plane of the observer's Meridian (axes PP′ and QQ′) lay off QCZ = Latitude, and rule axes ZN and HH′.
Lay off $ZCz = 108°$, and rule chord zz' parallel to HH′.
,, PCp = the Declination, and rule chord pp' parallel to QQ′.
Let these chords meet at X. Then X is the projection of the body on Twilight Parallel. The Hour Angle is then found as in Ex. 4.

PRINTED IN GREAT BRITAIN BY
NEILL AND CO., LTD.,
EDINBURGH.